SURFACE RADIATIVE ENVIRONMENT AT WAUSAU, WI

DURING THE FIRE CIRRUS IFO: OCT. 13 - NOV. 2, 1986

Lamont-Doherty Geological Observatory
Technical Report: LDGO-89-2

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ABSTRACT

Measurements of downwelling and upwelling shortwave and longwave irradiances were made at Wausau, Wisconsin from October 13 to November 2, 1986 as part of the First International Satellite Cloud Climatology Project Regional Experiment (FIRE) Cirrus Intensive Field Observation Program. These data, along with variables inferred from the measured irradiances, photo and video documentation of sky conditions and complimentary data gathered by other groups at Wausau have and continue to be of use in studies of cirrus and their impact on the surface radiative environment.

This report describes the Lamont-Doherty Geological Observatory IFO field experiment in detail and presents a comprehensive summary of project output. Examples of how project data have been used in cirrus studies also follow. These include documentation of a situation where differences in the thickness of cirrus affected the diffuse/direct nature of the downwelling shortwave irradiance but not the quantity of shortwave radiation reaching the surface. Also discussed is a method of distinguishing cirrus from clear skies or lower clouds which relies on differences in measured and inferred variables between the three systems. Finally, a summary of daily shortwave, longwave and net radiation totals for 12 days of the study period is presented.

1) INTRODUCTION

Despite general acceptance that clouds are among the most influential variables in the climate system, they remain one its least understood components. Spatial and temporal variations in cloud distribution are certain to play major roles in global climate change. However at present, differing compensations amongst cloud feedbacks in general circulation models are major contributors towards differences in regional and global climatic changes simulated by the models (Gates, 1988).

Cloud processes clearly remain in need of extensive investigation. This is no more true than for cirrus clouds. Cirrus have a large areal extent and may last for significant periods of time. They apparently can have large or small impacts on climate with a positive or negative sign, depending on the highly variable radiative properties of the cloud, the radiative characteristics of the underlying surface and on the height or radiating temperature of the cloud (FIRE, 1989). When run with doubled CO_2 and a coupled mixed-layer ocean, the United Kingdom Meteorological Office's GCM showed surface warming to be associated with an overall decrease of middle clouds and an increase in cirrus (Wilson and Mitchell, 1987).

The International Satellite Cloud Climatology Project (ISCCP) is a major long-term program to monitor clouds on a global scale (Schiffer and Rossow, 1983). The program is resulting in improved parameterizations of clouds in climate models and increased knowledge of the temporal and spatial distributions of clouds and the influence of clouds on atmospheric radiative and hydrological balances. The United States contribution to this program is the First ISCCP Regional Experiment (FIRE). This multi-year program is designed to validate and improve ISCCP algorithms, cloud/radiation models and cloud parameterizations in general circulation models (Cox et al., 1987). Specifically, improved understanding of cirrus and marine stratocumulus clouds is of greatest interest. FIRE activities include intensive field observations (IFO) and extended time observations of clouds in selected regions of the U.S.

A Cirrus IFO was conducted in Wisconsin in the autumn of 1986. Its objectives were to gain increased knowledge of the physical properties and physical processes of cirrus and to validate and improve retrievals of cirrus properties from satellite observations (FIRE, 1986; Starr, 1987). To help meet these goals, data were gathered from satellites, aircraft and ground stations. The latter included a network of stations within the study region at which downwelling shortwave and longwave irradiances were measured. These observations are essential for the validation of satellite-derived cloud and radiation estimates and for cloud and climate model development and validation efforts. This report concentrates on the irradiance program conducted at Wausau, WI by Lamont-Doherty Geological Observatory (LDGO) of Columbia University scientists (DAR has subsequently relocated to Rutgers University). Included is a description of the LDGO field program, summaries of the measured data and data-inferred products, and discussions of irradiance data on a key IFO study day, a cirrus recognition approach and daily net radiation.

2) LDGO FIELD PROGRAM

A) Irradiance measurements

Throughout the IFO, shortwave (SW) irradiance was measured at 18 sites throughout the southern half of Wisconsin (Figure 1). The LDGO station at Wausau Municipal Airport was part of this network and was one of 8 stations which measured both SW and longwave (LW) irradiance. These data have also been employed as ground truth for the Surface Radiation Budget Experiment (LeCroy et al., 1989; Whitlock and LeCroy, 1987).

Irradiance measurements at Wausau included:

1) full hemispheric downwelling SW (0.28-2.80 μm)

2) diffuse downwelling SW

3) full hemispheric downwelling near-infrared (NIR) (0.70-2.80 μm)

4) diffuse downwelling NIR

5) full hemispheric downwelling LW (4.0-50.0 μm)

6) full hemispheric upwelling LW (over a short grassy surface)

7) full hemispheric upwelling SW (over a short grassy surface)

Measurements were made using Eppley Precision Spectral Pyranometers (measuring SW) and Eppley Pyrgeometers (measuring LW). A Campbell CR-21 digital recorder recorded data as 1 minute averages of 10 second samples. These data subsequently were transferred to cassette tape and then dumped to 45 Mb removal disks using a Campbell C-20 cassette interface. Analyses were performed on Macintosh SE and II computers. The radiometers were calibrated with Colorado State University instruments at Madison, WI immediately prior to their installation at Wausau. Pyrgeometer output contains an adjustment for body temperature but not for dome temperature. Diffuse data were gathered using shade rings to shield the instruments from solar irradiance. These observations were adjusted for ring interference with incoming diffuse irradiance. All sensors were mounted one meter above the surface in the center of a large grassy field. Instruments were cleaned and leveled and shade rings adjusted several times a day.

Hemispheric SW and NIR fluxes were measured between October 13 and November 2, 1986. Some 96.8% of the data were successfully collected during this period (Figure 2). Diffuse and downwelling LW data were recorded between the 13th and the 30th or 31st, and were 95.6% to 96.9% complete. Upwelling LW was measured between the 19th and 2nd and was 95.5% complete. Upwelling SW fluxes were measured over the grassy field on several clear and cloudy days.

B) Photos and video

Photographs and videotapes of sky conditions were taken at selected intervals throughout the 20 day experiment. This provided detailed documentation of cloud type, percent cloud cover and the altitude of the visible cloud bases. Documentation included:

1) Fisheye (180^{o}) photos coincident with 21 overpasses of NOAA 9 or Landsat satellites covering 14 days of the IFO.

2) Stereo photos at 30 minute intervals during portions of the daylight hours on 12 days (130 pairs were collected).

3) Videotapes during portions of the daylight hours on 11 days (approximately 75 hours of coverage).

Complete listings of the times of photographs and video are found in Appendix 1.

C) Complimentary IFO data

1) Hourly meteorological observations made by Federal Aviation Administration personnel at the Wausau Municipal Airport included the general weather and specifics on temperature, pressure, humidity, precipitation, wind, visibility and clouds. Cloud observations included type, percent total and percent opaque cover, altitude of visible cloud bases and percent coverage of clouds at different levels.

2) As a part of a coincident Air Force project, 23 radiosonde launches over 14 days provided information on pressure, temperature, relative humidity, dew point, air density, wind direction and speed, N-S wind speed, E-W wind speed, speed of sound and index of refraction. Measurements were made at 500 m increments from the surface to approximately 15,000 m. Launch times are listed in Appendix 2.

3) Approximately 26 hours of lidar observations were made over 7 days by the University of Utah FIRE team headed by Dr. Kenneth Sassen. Intervals of data collection are listed in Appendix 2.

3) IRRADIANCE-INFERRED PRODUCTS

A number of variables were inferred from the irradiances measured at Wausau. These include:

1) full hemispheric downwelling (dwn) visible (VIS) irradiance (irrad) (0.28-0.70μm):

$$\text{VIS irrad} = \text{SW irrad} - \text{NIR irrad} \quad (1)$$

2) VIS diffuse (dif) irradiance:

$$\text{VIS dif} = \text{SW dif} - \text{NIR dif} \quad (2)$$

3) ratio of NIR to VIS irradiance:

$$\frac{\text{NIR irrad}}{\text{VIS irrad}} \quad (3)$$

4) fraction of diffuse irradiance (for SW, NIR and VIS):

$$\frac{\text{dif irrad}}{\text{hemispheric irrad}} \quad (4)$$

5) atmospheric transmissivity (TR) (for SW, NIR and VIS):

$$TR = \frac{\text{dwn irrad at the surface}}{\text{dwn irrad at top of atmosphere}} \quad (5)$$

dwn irrad at top of atmosphere between:

0.28-2.8 μm = 1327.1 W/m^2

0.28-0.7 μm = 632.4 W/m^2

0.7-2.8 μm = 694.7 W/m^2

6) optical depth (OD) (for SW, NIR and VIS):

$$OD = \cos ZA \ \ln \frac{\text{top of atmosphere irrad}}{\text{hemispheric irrad} - \text{dif irrad}} \quad (6)$$

where ZA = solar zenith angle

7) surface albedo over a short grassy field:

$$\text{albedo} = \frac{\text{SW upwelling (up) irrad}}{\text{SW dwn irrad}} \quad (7)$$

8) net irradiance (net) over representative surfaces:

$$net = SW\ dwn + LW\ dwn - SW\ up - LW\ up \qquad (8)$$

SW up was not measured continuously. Rather, albedo values of 0.23 ($TR \geq 0.40$) and 0.19 ($TR < 0.40$) were calculated from measurements made on several clear and cloudy days and applied to SW dwn data to infer continuous SW up values.

4) WAUSAU DATA ARCHIVING

The LDGO Wausau irradiance observations and irradiance-inferred products are archived at the NASA Climate Data System as well as at the Lamont-Doherty Geological Observatory. The photo and video data are also available at the Observatory.

5) PLOTS OF DAILY DATA

Five minute averages of irradiance and irradiance-inferred data are shown in graphic form for all IFO days in Appendix 3. Included are plots during the daylight hours of:

a) downwelling SW, NIR and VIS

b) diffuse downwelling SW, NIR and VIS

c) ratio of NIR to VIS irradiance

d) fraction of diffuse to full irradiance in the SW, VIS and NIR

e) SW, VIS and NIR transmissivities

f) optical depth in the SW, VIS and NIR

g) downwelling and upwelling LW irradiance

h) net surface irradiance

Downwelling and upwelling LW irradiances are also plotted for full days.

6) IFO ANALYSES

A) Cooperative efforts to date

Cooperative work with other IFO participants to date has included: a) investigations of surface radiative characteristics during the IFO (Whitlock et al., 1988; LeCroy et al., 1989), b) providing ground truth for the Surface Radiation Budget Experiment (Whitlock and LeCroy, 1987), c) study of cirrus cloud fraction and optical depth during the IFO (Whitlock et al., 1989), d) providing radiation data for a study of sub-visual cirrus (Sassen, 1989) and e) providing sky photographs and video for use in FIRE ground, aircraft and satellite investigations (e.g. to Heymsfield, Poole).

B) LDGO IFO analyses

1) October 28 cirrus episode

A cirrus deck was present across Wisconsin on October 28. At Wausau, the cirrus were periodically obscured by an altostratus deck with a base of approximately 3.5 km. Figure 3 illustrates the marked minute-to-minute and hour-to-hour variability of the downwelling shortwave irradiance, both full and diffuse. With heavier cloud cover, direct downwelling SW was almost absent, thus total and diffuse shortwave fluxes were approximately equal (ie. 20:00-20:30 GMT). When thin cirrus prevailed, high values of irradiation were measured, with about 80% of that radiation following a direct path through the atmosphere (ie. 18:10-19:10 GMT). When cirrus were somewhat thicker (ie. 17:30 GMT), total SW remained close to the morning cirrus values, however between 50% and 65% of the measured irradiance was diffuse. This variation in the quality but not the quantity of the SW flux in the presence of cirrus was noted several other times at Wausau and has been noted in Extended Time Observations at Palisades, NY.

2) Identification of cirrus

Irradiances and irradiance-inferred variables are shown for cirrus, stratus, clear and variable sky conditions in Figure 4. Midday hours are plotted, minimizing zenith angle effects. Skies were heavily overcast at Wausau on October 23. On the 27th, thin cirrus associated with an approaching warm front covered the sky and on the 29th skies were clear. As noted in the previous section, throughout much of the 28th stratus clouds obscured the cirrus at Wausau.

Relatively well-defined differences in certain variables under the different sky conditions suggests the potential employment of these data as cirrus indicators. To test this, hourly weather observations, sky photographs, sky video and lidar observations were used to identify specific intervals of non-cirrus clouds, cirrus and clear skies within two hours of noon on the four study days. Irradiance data from the selected intervals were then examined and thresholds or boundaries separating stratus, cirrus and clear skies were determined. Variables which were most distinctive for given sky conditions include: SW transmissivity, optical depth in the SW, diffuse fraction of SW, the ratio of NIR to VIS irradiance, the ratio of NIR diffuse to VIS diffuse, and LW irradiance. These are considered to be key indicators and are listed in Table 1 along with category thresholds.

Variables such as SW irradiance, SW transmissivity and the ratio of NIR diffuse to VIS diffuse proved inconclusive in distinguishing between cirrus and non-cirrus clouds and/or cirrus and clear conditions. For instance, a SW transmissivity threshold of 0.67 separates non-cirrus clouds from cirrus quite well, however it is difficult to distinguish cirrus from clear skies using transmissivity. This appears to be due to: 1) difficulties in differentiating between cirrus and clear in the visual observations, photos and video, 2) the lack of a specific broad-band shortwave signature which distinguishes cirrus from lower level haze, and 3) the zenith angle dependence of transmissivity.

The utility of this threshold approach in delineating sky conditions was tested using data from the remaining 17 IFO days. Encouraging results were noted. Examples from 2 of the 17 days are shown in Figure 5. Intervals of either clear skies or cirrus (ie. no middle or low level clouds) are illustrated in the top graph of each figure, while the bottom graph indicates where skies were clear. Between 15:00 and 18:00 on October 20 (5A), scattered mid-level clouds, haze and cirrus were present, as indicated by the broken nature of the cirrus or clear indicators and the absence of a signal from four of the five clear indicators. A non-cirrus cloud episode prevailed between 18:00 and 20:00 GMT, as evidenced by the absence of cirrus or clear indicators. After 20:00 cirrus became the dominant cloud type. On the 17th (5B), skies were cloudy in the morning and then cleared up in the afternoon. Most of the indicators in the top portion of the figure suggest that the morning was dominated by non-cirrus cloud cover, with either a cirrus or clear afternoon. The bottom portion of the figure indicates that the afternoon was primarily clear.

It is apparent when examining Figure 5 that it would be ill advised to rely on any one variable as the sole indicator of sky conditions. Rather, judgement should be based on the extent of agreement amongst all the indicator variables. For instance one can be confident that skies were not clear on the 20th, although the NIR/VIS clear threshold was exceeded throughout a good portion of the period. The latter suggests that the cirrus were particularly thin. Also, on the morning of the 17th the disagreement amongst the variables as to whether cirrus or stratus were present suggests that while stratus were probably abundant, they were not too thick. All inferences made on these two days generally agree with independent observations.

Studies concerning this threshold evaluative technique are continuing. This includes the development of multi-indicator thresholds and extending thresholds to early and late day periods. Data gathered at the FIRE Extended Time Observation site in Palisades, NY will be used to test the IFO results and identify potential site and seasonal specifics.

3) Daily radiation

Daily totals of downwelling and upwelling SW and LW radiation between October 19 and 30, 1986 are shown in Table 2. Data are also separated by day and night time hours (approximately 11 and 13 hours, respectively at this time of the year). Gaps within the study period were filled by linear interpolation. Totals on most days were an integration of irradiances measured under multiple atmospheric conditions. However, on October 19 skies were clear throughout the day and night, with the exception of fog around sunrise and scattered cirrus in the evening. Daytime haze resulted in horizontal visibilities at the surface of about 16 km. Compared to other study days, downwelling SW was high on the 19th (11.2 MJ/m^2) and downwelling LW was low during the daylight hours (8.1 MJ/m^2) and at night (12.4 MJ/m^2). The net 24 hour total of +4.1 MJ/m^2 was among the highest of the experiment period.

October 23 provided the best example of radiation totals under stratus clouds. Cloud bases ranged from a few hundred meters to two thousand meters and visibility from about 1 to 10 km during the 24 hour period. The downwelling SW total of 2.4 MJ/m^2 was about 20% of the clear-day value, while the daytime downwelling longwave total of 13.1 MJ/m^2 was 162% of the clear total. Other up and downwelling LW totals were approximately 125% of clear totals. Net radiation on the 23rd was slightly positive (+0.8 MJ/m^2).

No full-day episodes of solely cirrus occurred during the IFO. An examination of daylight radiation totals measured under similar zenith angles suggested that the presence of cirrus increased downwelling LW compared to clear skies. However, several percent lower downwelling SW and a larger LW upwelling total under cirrus skies resulted in somewhat lower net total radiation with thin cirrus present than when skies were clear. These observations should be considered time and site specific. They may also be at least a partial function of other variables, such as precedent surface and

atmospheric conditions and atmospheric moisture and aerosol characteristics at the times of observation.

7) CONCLUSIONS

The LDGO field program conducted at Wausau, WI during the FIRE Cirrus IFO was successful in gathering virtually complete observations of shortwave and longwave irradiances. These data, along with variables inferred from the measured irradiances, photo and video documentation of sky conditions and complimentary data gathered by other groups at Wausau have and continue to be of use in investigations of cirrus and their impact on the surface radiative environment. Examples of such studies have been presented here. They include documentation of a case where differences in the thickness of cirrus affected the diffuse/direct nature of the downwelling shortwave irradiance but not the quantity of radiation reaching the surface. Also, a method of distinguishing cirrus from clear skies or lower clouds has also been developed from the study data. This approach relies on differences in measured and inferred variables between the three systems. For instance, notable differences were observed between cirrus and clear sky systems in terms of optical depth in the SW, the diffuse SW fraction and SW transmissivity. Differences between cirrus and lower and thicker clouds were observed in the NIR diffuse to VIS diffuse ratio, optical depth in the SW, the fraction of SW diffuse, and LW irradiance. Finally, a summary of daily shortwave, longwave and net radiation totals for 12 days of the study period showed marked differences between clear and cloudy days and comparisons of mid-day totals under thin cirrus and clear skies suggested a slight decrease in net radiation when cirrus were present.

The LDGO Wausau irradiance observations and inferred variables are archived with the NASA Climate Data System as well as at the Lamont-Doherty Geological Observatory (where the photo and video data are also available). Using these observations, along with

FIRE Extended Time Observations from Palisades, NY, cirrus and surface irradiance related issues continue to be addressed. These include 1) validation of the ISCCP cloud detection algorithm and ISCCP models which infer surface and cloud properties, 2) comparison of cirrus and clear sky impacts, 3) subresolution cirrus, single and multiple cirrus layers, cirrus of different altitudes and thickness and cirrus when lower cloud decks are present and 4) cirrus and clear sky climatologies.

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REFERENCES:

Cox, S.K., D.S. McDougal, D.A. Randall and R.A. Schiffer (1987). FIRE - the first ISCCP Regional Experiment. *Bulletin of the American Meteorological Society* 68, 114-118.

FIRE (1986). *FIRE Cirrus Intensive Field Observations: 1986 Operations Plans*, 81pp & appendices.

FIRE (1989). *FIRE II Research Plan: A Component of the U.S. Cloud Climate Research Program*. Prepared by the FIRE Project Office and FSET Working Group Participants.

Gates, W.L. (1988). Status of global model simulations of climatic effects of increased atmospheric carbon dioxide. *Report of the Fourth Session of the CAS/JSC Working Group on Numerical Experimentation*, WMO/TD No. 278, appendix B, 7pp.

LeCroy, S.R., C.H. Whitlock, L.R. Poole, J.M. Alvarez, D.A. Robinson, D.O'C. Starr and S.K. Cox (1989). Surface radiation observations of cirrus cloud properties during the Wisconsin FIRE/SRB Experiment. *Proceedings of the International Radiation Symposium, IRS 88*, A. Deepak Publishing, Hampton, VA.

Sassen, K., M. Griffin and G. Dodd (1989). Optical scattering and microphysical properties of subvisual cirrus clouds and climatic implications. *Journal of Applied Meteorology* 28, 91-98.

Schiffer, R.A. and W.B. Rossow (1983). The International Satellite Cloud Climatology Project (ISCCP) - The first project of the World Climate Research Program. *Bulletin of the American Meteorological Society* 64, 779-784.

Starr, D. O'C. (1987). A cirrus-cloud experiment: Intensive Field Observations planned for FIRE. *Bulletin of the American Meteorological Society* 68, 119-124.

Whitlock, C.H. and S.R. LeCroy (1987). Heat budget observations for the FIRE/SRB Wisconsin Experiment Region from October 9 through November 2, 1986. *NASA Technical Memorandum* 89159, 33pp.

Whitlock, C.H., L.R. Poole, J.M. Alvarez, D.A. Robinson, C. Grund, K. Sassen, D.O'C. Starr, S.K. Cox, S.R. LeCroy, R. Frouin and G. Smith (1989). Cirrus cloud fraction and optical depth from surface observations during the Wisconsin FIRE/SRB Experiment. *Monthly Weather Review*, in press.

Whitlock, C.H., L.R. Poole, S.R. LeCroy and D.A. Robinson (1988). Surface radiation observations for October 27-28, 1986 during the Wisconsin FIRE/SRB Experiment. *Proceedings of the FIRE Science Team Workshop*, Vail, CO, 167-170.

Wilson, C.A. and J.F.B. Mitchell (1987). A doubled CO_2 sensitivity experiment with a global climate model including a simple ocean. *Journal of Geophysical Research*, 92, 13315-13344.

Table 1. Thresholds delimiting non-cirrus cloud, cirrus and clear sky systems derived from selected Wausau data.

INDICATOR	CIRRUS / NON-CIRRUS	CIRRUS/CLEAR
SW transmissivity	$\geq^*$ 0.67	inconclusive
fraction SW diffuse	$\leq$ 0.30	$\geq^*$ 0.15
SW optical depth	$\leq$ 0.30	$\geq$ 0.24
NIR/VIS	$\geq$ 1.00	$\leq$ 1.10
NIR diffuse / VIS diffuse	inconclusive	$\geq$ 0.12
LW irradiance	$\leq$ 320 watts/m^2	$\geq$ 260 watts/m^2

*sign refers to what constitutes cirrus

Table 2. Daily radiation totals for October 19 to 30 at Wausau. Included are SW and LW totals for the day and night hours and for the entire 24 hour period. Also shown are net values. Totals are in MJ/m^2.

		downwelling		upwelling		Net
		SW	LW	SW	LW	
10/19	day	11.2	8.1	2.5	10.9	+5.9
	night	-	12.4	-	14.2	-1.8
	24 hr	11.2	20.5	2.5	25.1	+4.1
10/20	day	10.7	12.0	2.2	14.1	+6.4
	night	-	13.3	-	15.5	-2.2
	24 hr	10.7	25.3	2.2	29.6	+4.2
10/21	day	11.1	12.1	2.4	14.8	+6.0
	night	-	14.3	-	16.0	-1.7
	24 hr	11.1	26.4	2.4	30.8	+4.3
10/22	day	6.2	12.4	1.3	14.3	+3.0
	night	-	15.0	-	16.7	-1.7
	24 hr	6.2	27.4	1.3	31.0	+1.3
10/23	day	2.4	13.1	0.5	13.6	+1.4
	night	-	16.0	-	16.6	-0.6
	24 hr	2.4	29.1	0.5	30.2	+0.8
10/24	day	4.0	10.3	0.9	10.8	+2.6
	night	-	15.5	-	15.9	-0.4
	24 hr	4.0	25.8	0.9	26.7	+2.2
10/25	day	7.4	10.7	1.6	12.3	+4.2
	night	-	13.5	-	15.3	-1.8
	24 hr	7.4	24.2	1.6	27.6	+2.4

		downwelling		upwelling		Net
		SW	LW	SW	LW	
10/26	day	4.8	12.4	1.1	13.1	+3.0
	night	-	15.4	-	15.8	-0.4
	24 hr	4.8	27.8	1.1	28.9	+2.6
10/27	day	11.0	7.7	2.5	10.9	+5.3
	night	-	12.6	-	15.0	-2.4
	24 hr	11.0	20.3	2.5	25.9	+2.9
10/28	day	8.2	12.5	1.8	14.5	+4.4
	night	-	14.4	-	15.6	-1.2
	24 hr	8.2	26.9	1.8	30.1	+3.2
10/29	day	11.1	7.9	2.4	11.1	+5.5
	night	-	14.0	-	15.5	-1.5
	24 hr	11.1	21.9	2.4	26.6	+4.0
10/30	day	8.8	8.3	1.9	10.6	+4.6
	night	-	12.5	-	14.8	-2.3
	24 hr	8.8	20.8	1.9	25.4	+2.3

Figure 1. Shortwave surface radiation sites in the FIRE/Surface Radiation Budget Experiment network. Longwave data were collected at Adams, Baraboo, Fort McCoy, Madison, Oshkosh, Stevens Point, Wausau and Wautoma. (from LeCroy et al.,1989)

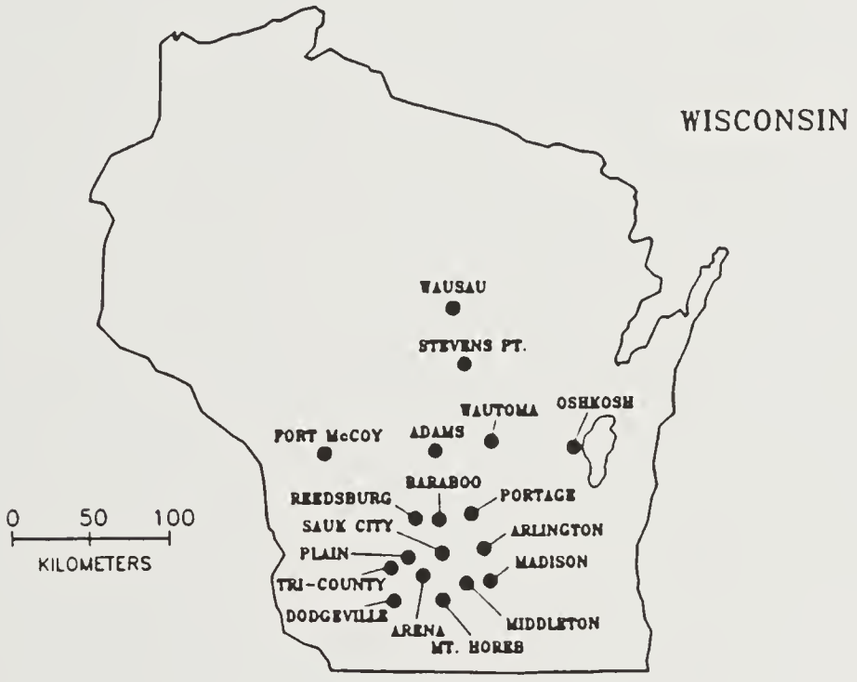
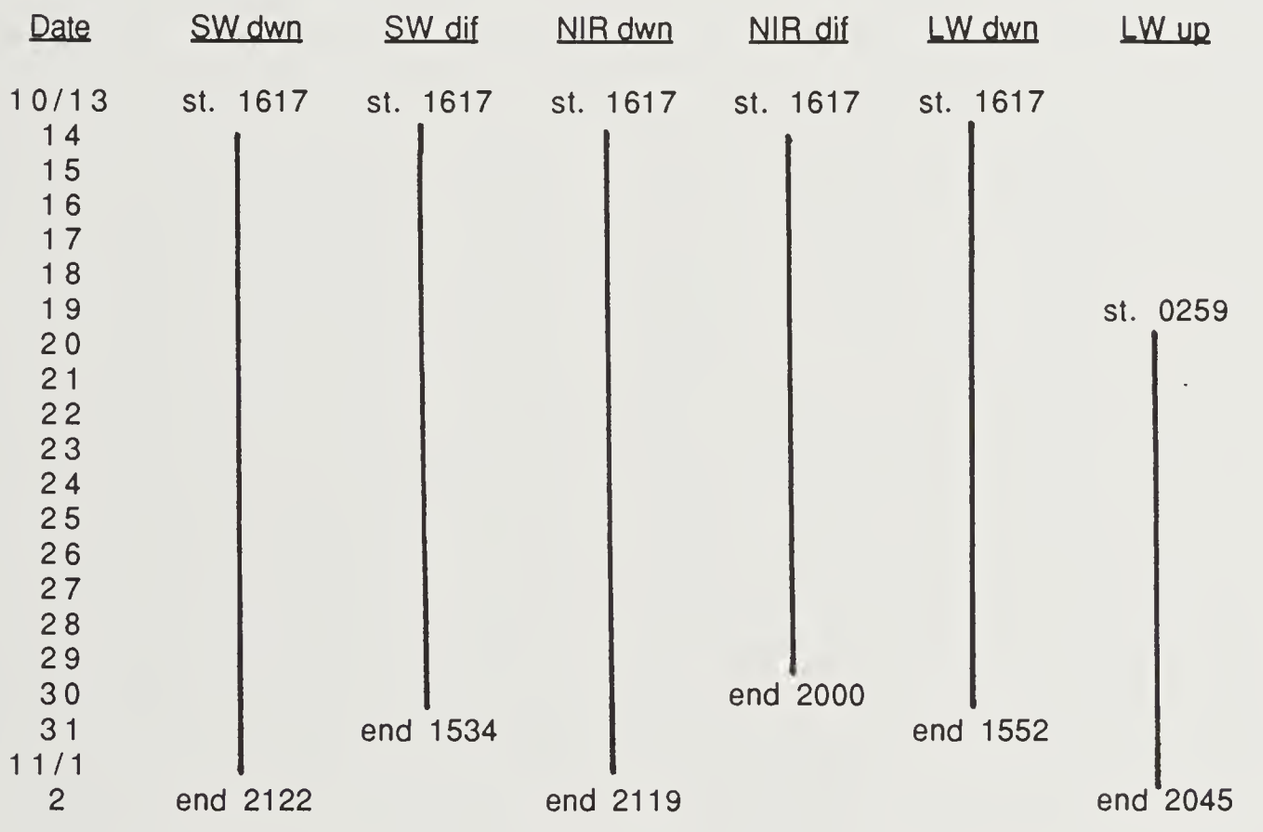


Figure 2. Intervals during which virtually complete irradiance data were gathered at Wausau during the Cirrus IFO. Times are in GMT (GMT = CST + 6 hrs). st. = start, min. = minutes.

SW dwn = downwelling shortwave irradiance (0.28-2.80 μm)
SWdif = diffuse downwelling shortwave irradiance
NIR dwn = downwelling near-infrared irradiance (0.70-2.80 μm)
NIR dif = diffuse downwelling near-infrared irradiance
LW dwn = downwelling longwave irradiance (4.0-50.0 μm)
LW up = upwelling longwave irradiance (over a short grassy surface)



	SW dwn	SW dif	NIR dwn	NIR dif	LW dwn	LW up
total min.	29206	25928	29203	24804	25946	21276
miss. min.	934	804	934	1095	830	967
% missing	3.2	3.1	3.2	4.4	3.2	4.5

Figure 3. Shortwave, near-infrared and longwave irradiances at Wausau, WI during the daylight hours of October 28, 1986. Data are plotted at one minute intervals, with the exception of several periods (ie. 1530-1640 GMT) where data are missing. Also shown are the approximate times of radiosonde launches, satellite overpasses, sky photographs and videotaping of sky conditions.

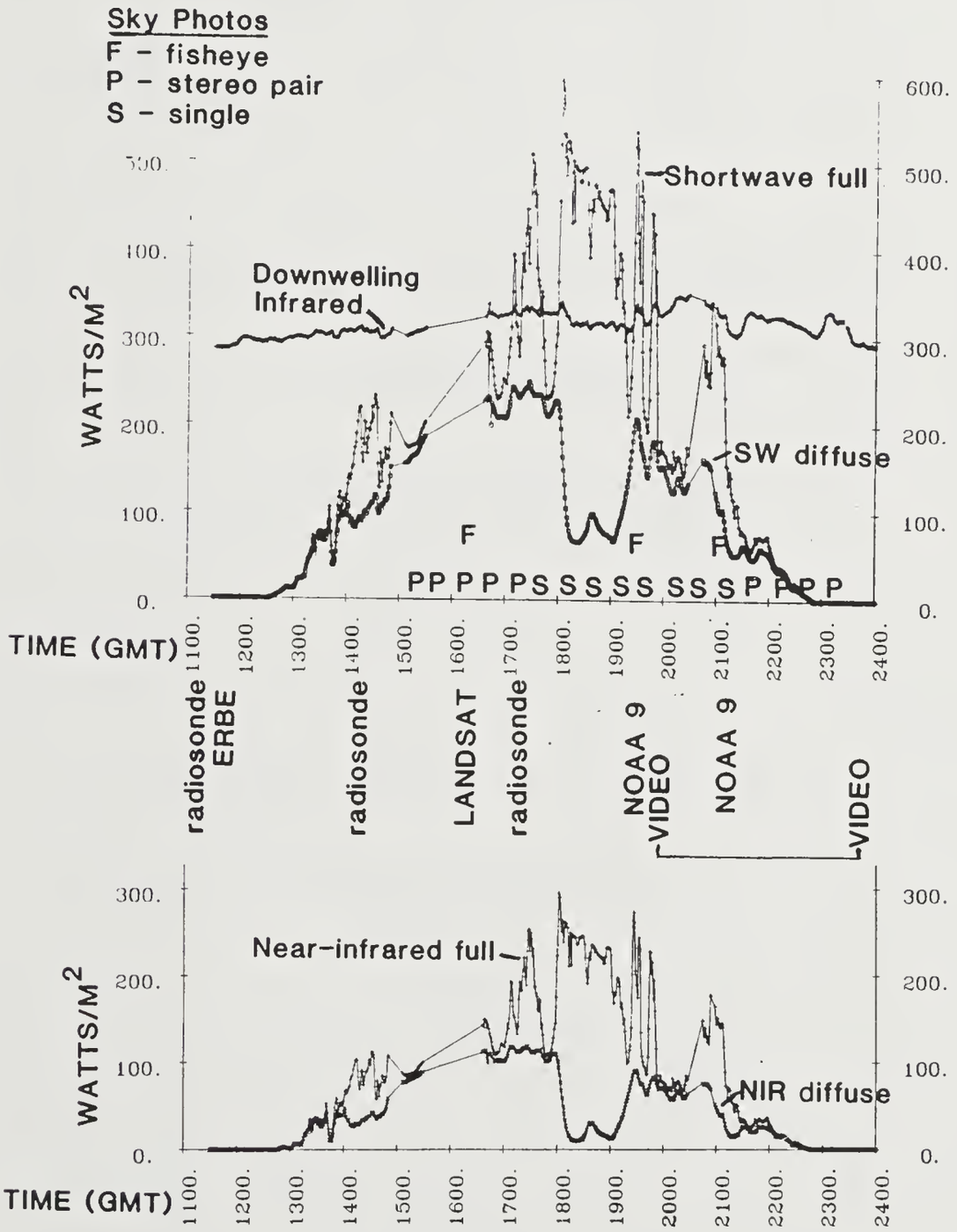
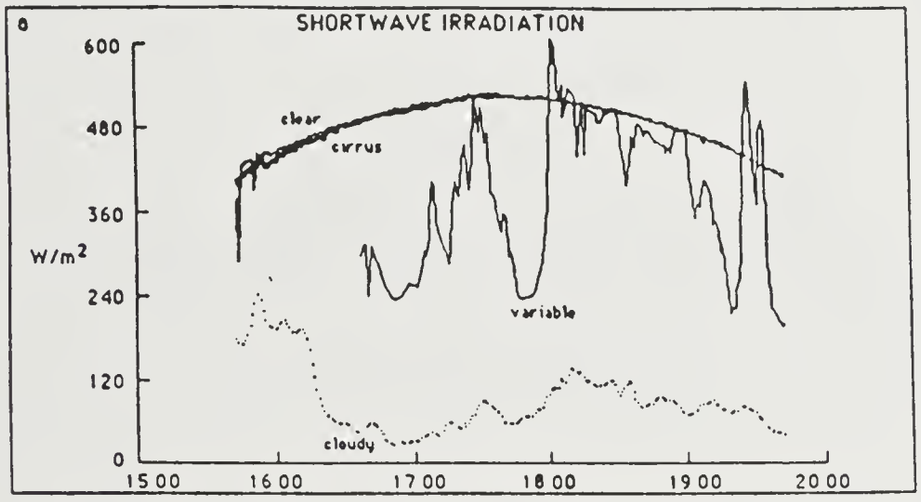
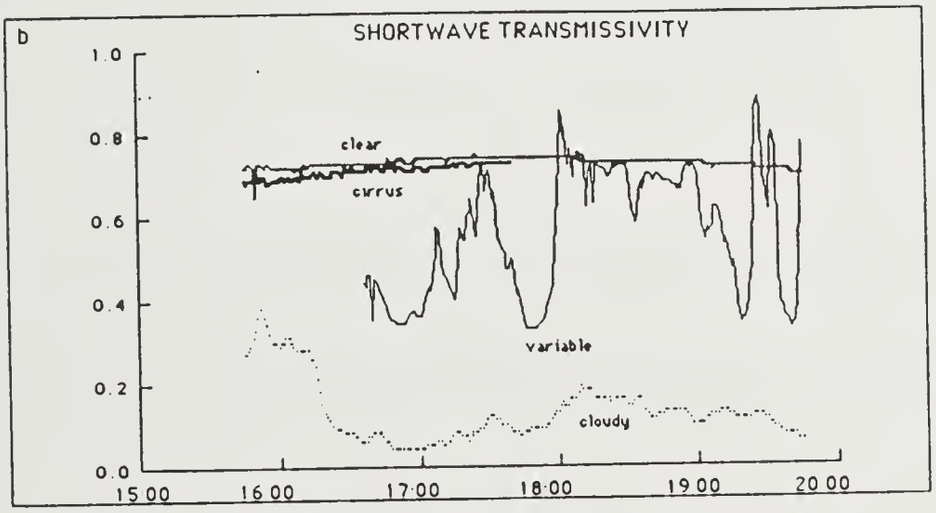
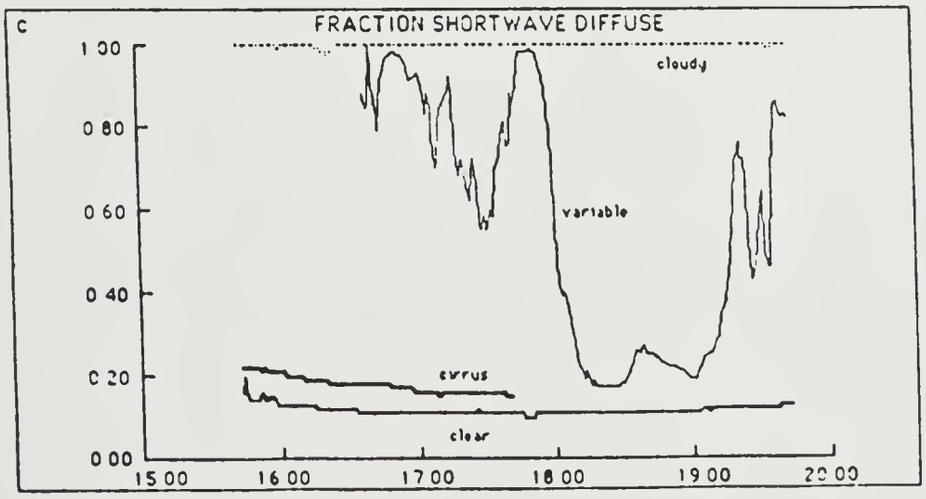
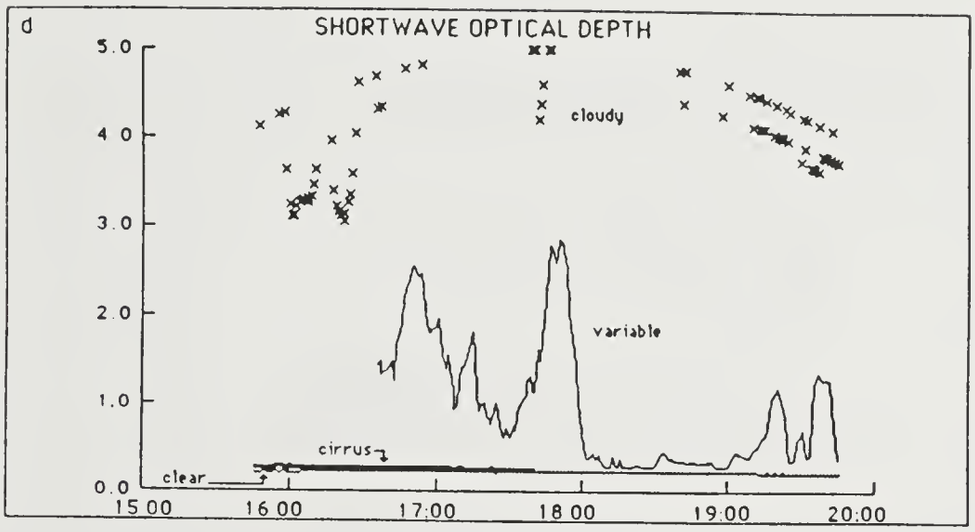


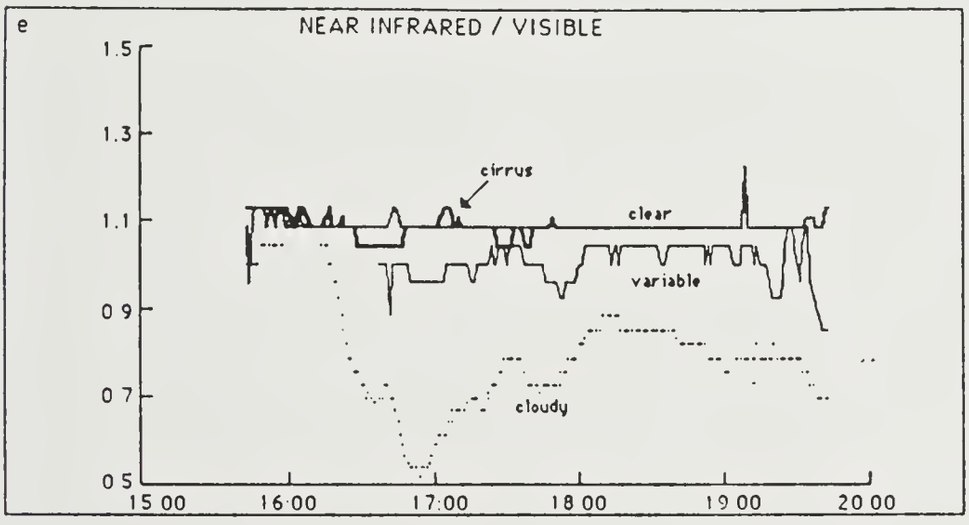
Figure 4. Mid-day irradiances and associated atmospheric variables at Wausau, WI on October 23 (cloudy), 27 (cirrus), 28 (variable) and 29 (clear), 1986. Time in GMT. Data are missing after 17:45 on the 27th and before 16:30 on the 28th.

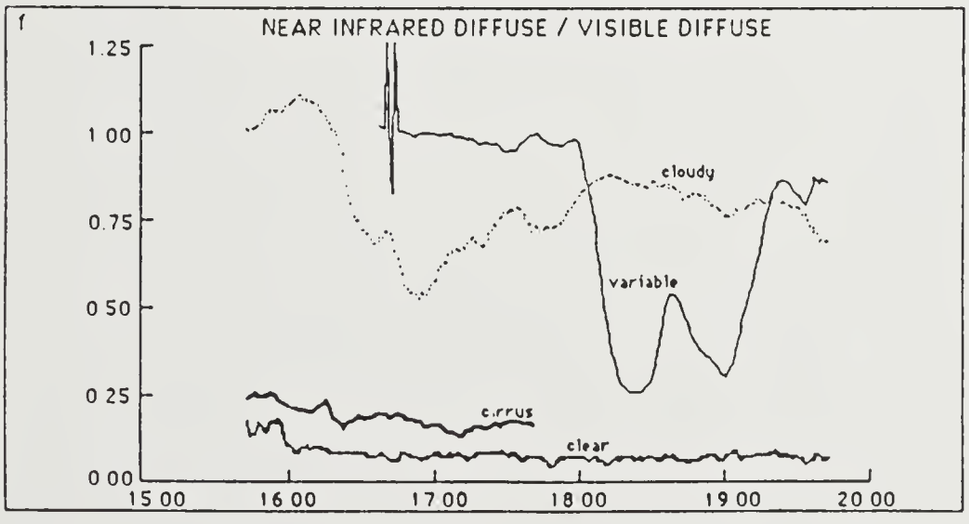







d
SHORTWAVE OPTICAL DEPTH
5.0
4.0
3.0
2.0
1.0
0.0
cloudy
variable
cirrus
clear
15 00
16 00
17:00
18 00
19:00
20:00


e
NEAR INFRARED / VISIBLE
1.5
1.3
1.1
0 9
0 7
0 5
cirrus
clear
variable
cloudy
15 00
16:00
17:00
18 00
19 00
20 00


f
NEAR INFRARED DIFFUSE / VISIBLE DIFFUSE
1.25
1 00
0.75
0 50
0 25
0 00
cloudy
variable
cirrus
clear
15 00
16 00
17 00
18 00
19 00
20 00

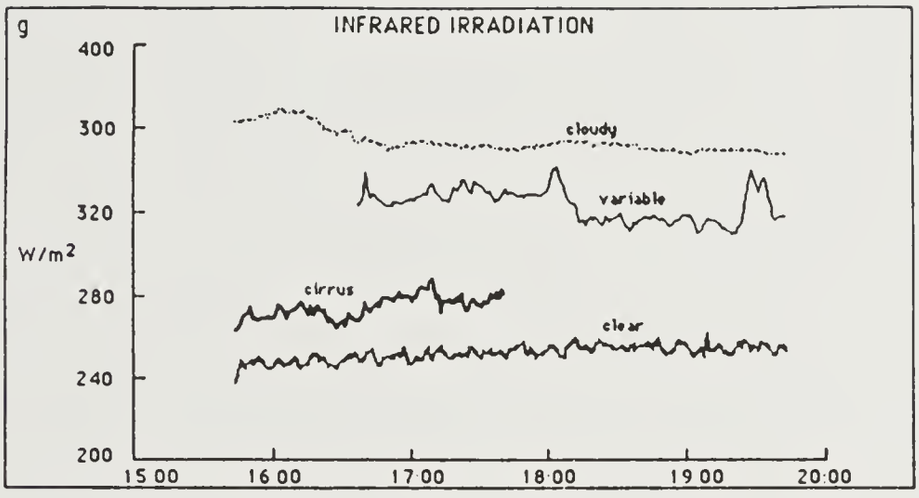
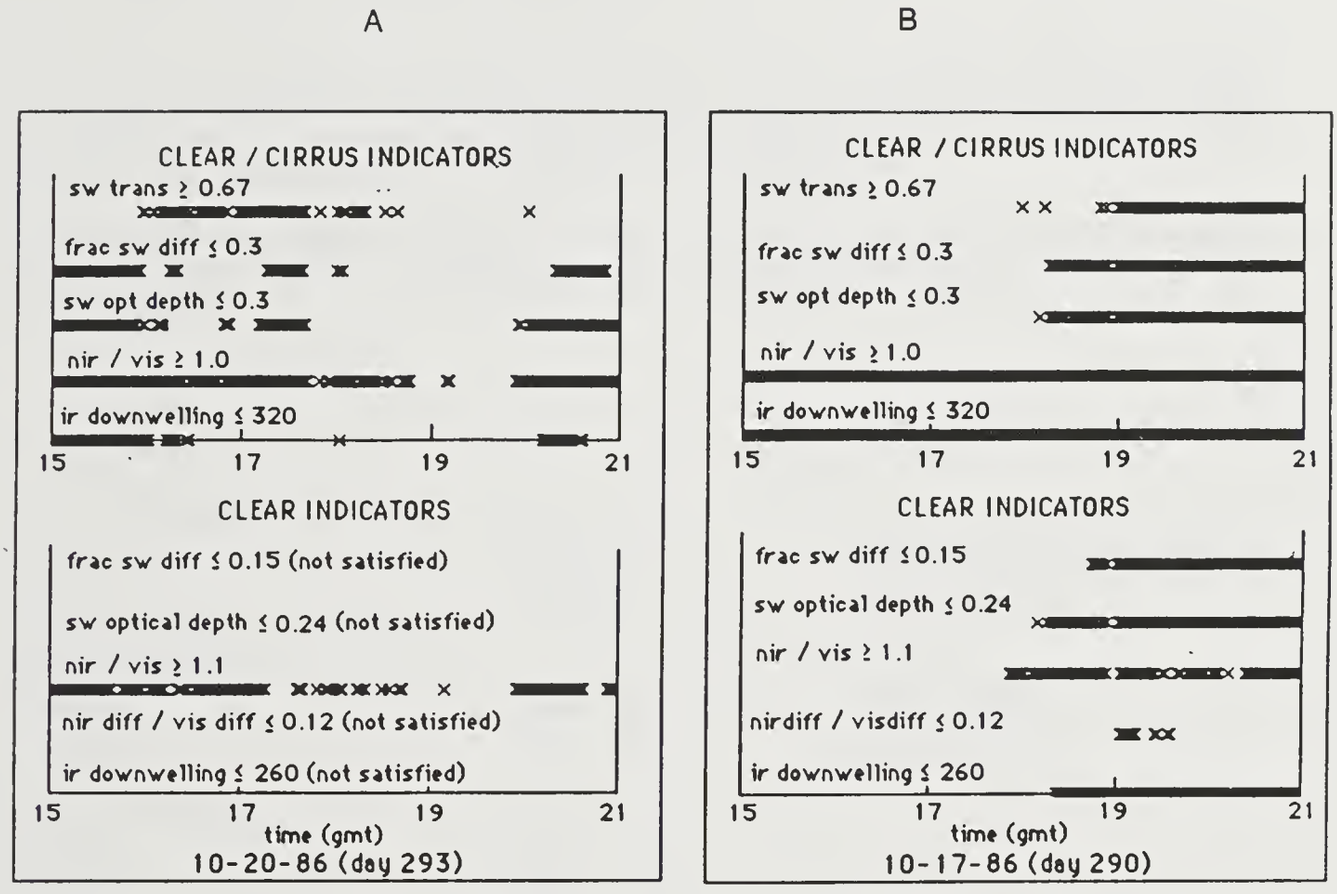

g
INFRARED IRRADIATION
400
300
320
W/m2
280
240
200
cloudy
variable
cirrus
clear
15 00
16 00
17 00
18 00
19 00
20:00

Figure 5. Temporal distribution of cirrus or clear skies (top) and clear skies (bottom) at Wausau on October 20 and October 17, 1986 as inferred from key indicators. Intervals when thresholds were exceeded are marked with X's or lines.



APPENDIX 1.

A) Photographs and videotapes of sky conditions taken at the Wausau Municipal Airport during the FIRE IFO (Oct. 15 - Nov. 2, 1986). All photos are archived at the Lamont-Doherty Geological Observatory as 35mm slides. The list includes:

1) Time of the photograph(s) (GMT) (GMT = CST + 6 hrs)

2) Type of photo: a) fish=fisheye (180°), b) pair=stereo pair, single-wide angle (24mm) nadir oriented, c) oblique=wide angle at some angle away from nadir. When more than one of a particular type is taken the number is shown in parentheses. Fisheyes were usually taken with ultraviolet and orange filters.

3) Remarks: Satellite overpasses coinciding with photos are listed along with the satellite viewing zenith. If a pass differs by more than 5 minutes of a photo the pass time is listed.

Time (GMT)	Type	Remarks
Date: 10/15/86		
1551	Fish (3)	ERBS (22° viewing zenith)
2001	Fish (2)	NOAA 9 (24°)
Date: 10/16/86		
1555	Fish (2)	ERBS (22°)
1955	Fish (2)	NOAA 9 (36°)
Date: 10/17/86		
1455	Fish	
1500	Fish	
1512	Single (2)	
1542	Single	
1605	Fish (2)	ERBS (53°)
1642	Single	
1712	Single	
1742	Single	
1812	Single	
1842	Single	
1842-1912	Single (3)	
1850	Fish (2)	
1912	Pair	
1942	Pair	
2012	Pair	
2042	Pair	
2112	Pair	NOAA 9 (64°) at 2122
2142	Pair	
2212	Pair	

Date: 10/18/86		
1440	Fish (2)	ERBS (28°)
Date: 10/19/86		
1448	Fish (2)	ERBS (14°)
1503	Single	
1511	Fish (2)	
1533	Pair	
1603	Pair	
1608	Fish (2)	Landsat
1633	Single	
1703	Single	
1733	Single	
1803	Single	
1833	Single	
1903	Single	
1933	Pair	
2003	Pair	
2033	Pair	
2103	Pair	NOAA 9 (57°)
2133	Pair	
2203	Pair	
2233	Pair	
Date: 10/20/86		
1300	Oblique	
1316	Single (2)	ERBS (55°)
1346	Pair	
1416	Single	
1446	Single	ERBS (49°) at 1500
1516	Single	
1546	Single	
1616	Pair	
1635-1700	Oblique (7)	
1645	Single	
1649	Single	
1651	Single	
1721	Pair	
1751	Pair	
1821	Pair	NOAA 9 (65°) at 1909
2121	Pair	NOAA 9 (40°) at 2049
2151	Pair	
2221	Pair	
2251	Pair	

Date: 10/21/86		
1601	Single (2)	Landsat
1631	Pair	
1657	Fish (2)	
1701	Pair	
1731	Pair	
1801	Pair	
1831	Pair	
1901	Pair	NOAA 9 (70^{o})
1931	Pair	
2001	Pair	
2031	Pair	NOAA 9 (28^{o})
2101	Pair	
2131	Single	
2201	Single	
2231	Single	
2301	Single	
Date: 10/22/86		
1311-1344	Oblique (17)	ERBS (6^{o}) at 1344
1512	Single (2)	
1542	Pair	
1612	Pair	
1642	Pair	
1712	Pair	
1742	Pair	
1812	Pair	
1842	Pair	
1912	Pair	
1942	Pair	
2012	Pair	
2042	Pair	NOAA 9 (14^{o}) at 2028
2112	Pair	
2142	Pair	
2212	Pair	
Date: 10/24/86		
2010-2030	Fish (4)	NOAA 9 (19^{o}) at 2006
Date: 10/25/86		
1300-1350	Oblique (13)	ERBS (5^{o}) at 1240 1300-
1350	Fish (7)	
1700-1714	Oblique (13)	
1830-1930	Fish (5)	
1830-1930	Oblique (10)	NOAA 9 (32^{o}) at 1956
2036-2039	Oblique (4)	

Date: 10/26/86		
1848	Single (2)	
1918	Pair	
1948	Pair	NOAA 9 (43°) at 1945
2018	Pair	
2048	Pair	
2118	Pair	
2148	Pair	
2218	Single	
Date: 10/27/86		
1616	Pair	
1646	Pair	
1716	Pair	
1746	Pair	
1816	Pair	
1846	Pair	
1916	Pair	
1946	Pair	NOAA 9 (52°) at 1934
2016	Pair	
2046	Pair	
2116	Single	NOAA 9 (60°) at 2115
2146	Single	
2216	Single	
2246	Single	
Date: 10/28/86		
1358-1420	Oblique (5)	
1510	Single	
1511	Single	
1514	Single (2)	
1544	Pair	
1614	Pair	
1614	Fish (2)	Landsat at 1605
1644	Pair	
1714	Pair	
1744	Single	
1814	Single	
1844	Single	
1914	Single	
1926	Fish (2)	NOAA 9 (58°)
1944	Single	
2014	Single	
2044	Single	
2105	Fish (2)	NOAA 9 (53°)
2114	Single	
2144	Pair	
2214	Pair	
2244	Pair	
2314	Pair	

Date: 10/29/86		
1730	Oblique (2)	
1815	Oblique (2)	
1830	Single (2)	
1832	Pair	
1840	Oblique (2)	
1902	Pair	NOAA 9 (64°) at 1913
1932	Pair	
2002	Pair	
2032	Pair	
2102	Pair	NOAA 9 (44°) at 2053
2132	Pair	
Date: 10/30/86		
1500-1513	Oblique (10)	
1634	Single (2)	
1704	Pair	
1734	Pair	
1804	Pair	
1834	Pair	
1904	Pair	
1934	Single	
1920	Fish (2)	NOAA 9 (68°) at 1903
2004	Pair	
2034	Pair	NOAA 9 (32°) at 2043
2104	Pair	
2134	Pair	
2204	Pair	
2234	Pair	
2304	Single	
Date: 11/1/86		
1500-1525	Oblique (33)	
1500	Single (2)	
1721	Single (2)	
1751	Single	
1821	Single	
1851	Single	
1921	Pair	
1951	Pair	
2021	Pair	NOAA 9 (3°)
2035	Fish	
2051	Pair	
2121	Pair	
2151	Single	

Date: 11/2/86

1606	Pair	
1636	Pair	
1706	Pair	
1736	Pair	
1806	Pair	
1836	Pair	
1906	Pair	
1936	Pair	
2006	Pair	NOAA 9 (14^{o}) at 2011
2036	Pair	
2106	Pair	
2136	Pair	
2206	Pair	
2200-2210	Oblique (3)	
2213-2222	Oblique (6)	

B) Sky conditions at Wausau were videotaped at selected intervals during the Cirrus IFO. The following lists the dates and times (GMT) for which tapes are available. The 0.5" VHS tapes are archived at the Lamont-Doherty Geological Observatory.

Date:(October)	Time on-off	Elapsed Time
15	15:20-20:00	4:40
16	15:15-18:39	3:24
20	13:39-19:19, 19:41-23:39	9:38
21	16:28-19:42, 21:30-22:44	4:28
22	14:32-18:35, 18:46-20:55	6:12
25	19:03-21:28	2:25
26	19:15-21:37	2:22
27	18:00-23:45	5:45
28	19:57-23:47	3:50
29	18:13-20:35	2:22
30	16:48-20:39	3:51

APPENDIX 2.

A) Radiosonde launch times at Wausau during the IFO.

Date (October)	Launch (GMT)
13	12:37
15	11:46
16	9:48
	15:00
	17:20
17	10:52
19	10:58
20	8:54
21	11:44
22	11:06
	15:58
	14:04
23	17:06
24	16:01
25	18:55
26	16:03
27	9:51
	14:01
	17:00
	20:01
28	10:07
	13:02
	16:06

B) Intervals when the University of Utah's lidar was in operation at Wausau during the IFO.

Date:	Time on-off	Elapsed Time
10/22	13:30-18:30	5:00
10/25	18:50-20:12	1:22
10/27	17:50-20:19	2:29
10/28	14:50-21:30	6:40
10/30	19:35-23:15	2:40
11/1	17:58-21:22	3:24
11/2	17:10-21:20	4:10

APPENDIX 3.

A) Five minute averages of measured irradiances and variables inferred from the measured values. Included are plots during the daylight hours of:

a) downwelling SW, NIR and VIS (full irradiance)

b) diffuse downwelling SW, NIR and VIS (diffuse irradiation)

c) ratio of NIR to VIS irradiance

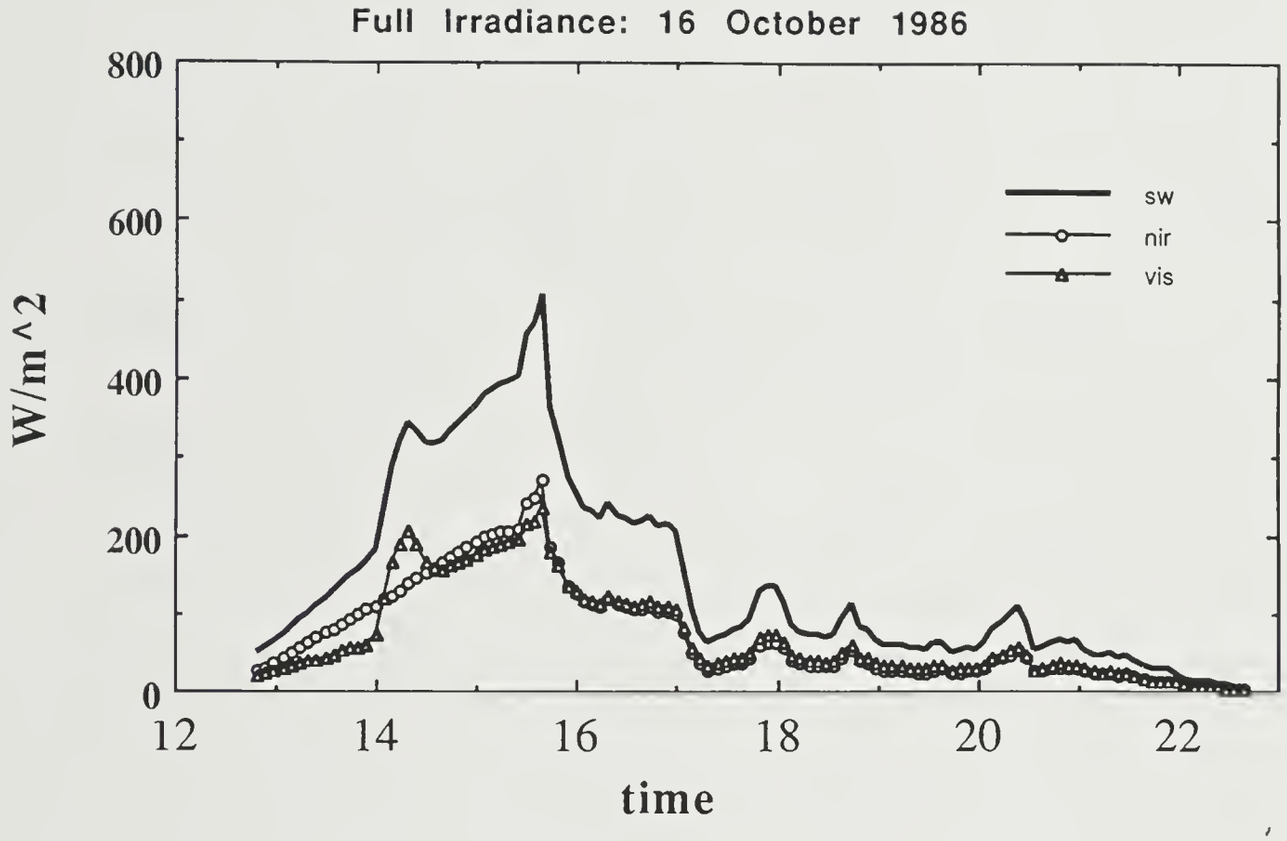
d) ratio of diffuse to full irradiance in the SW, VIS and NIR (fraction diffuse irradiance)

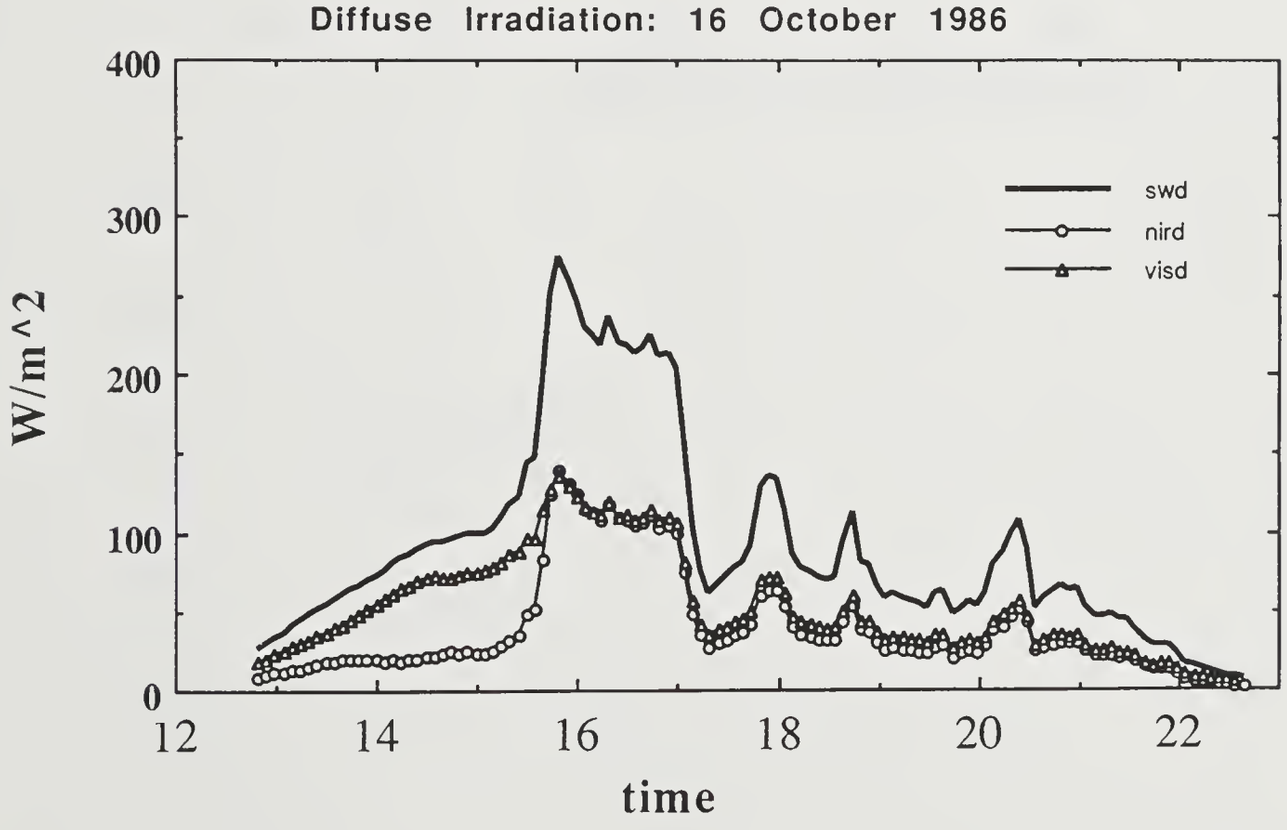
e) SW, VIS and NIR transmissivities

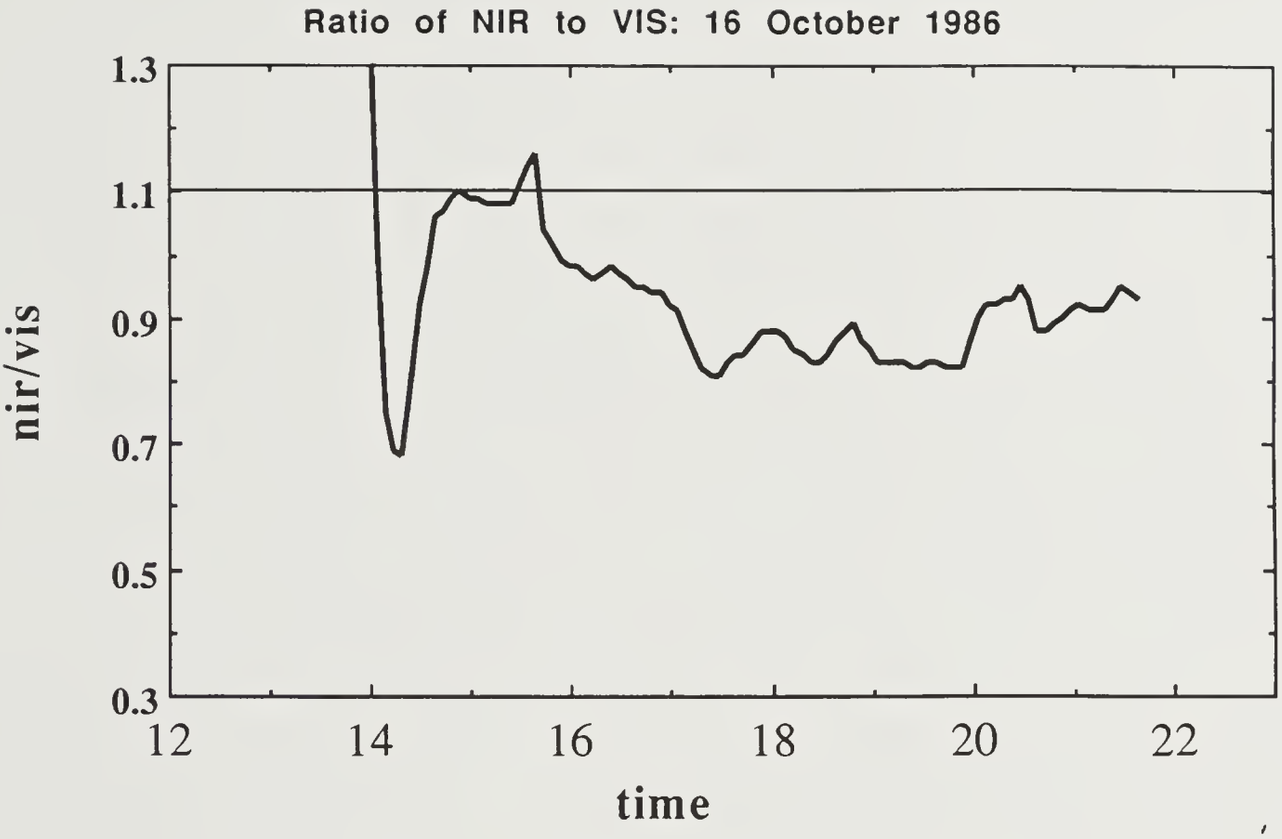
f) optical depth in the SW, VIS and NIR

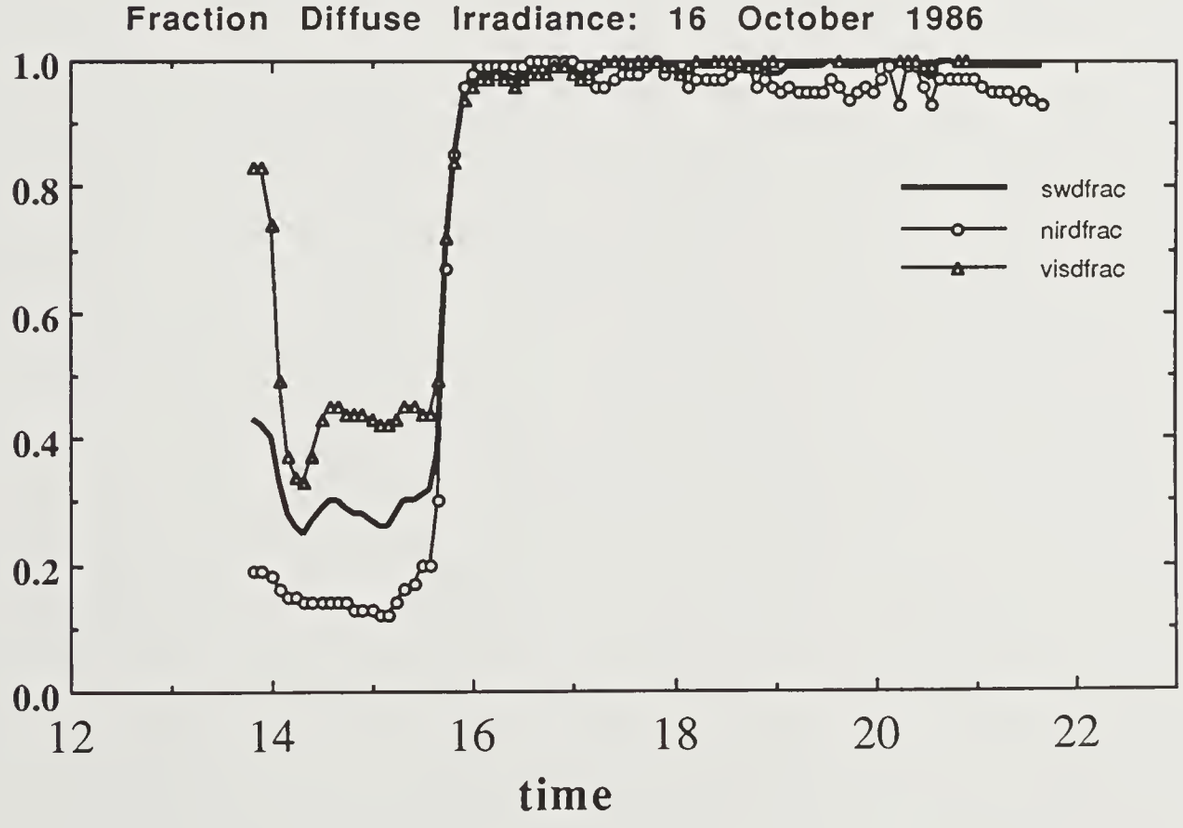
g) longwave (infrared) irradiance

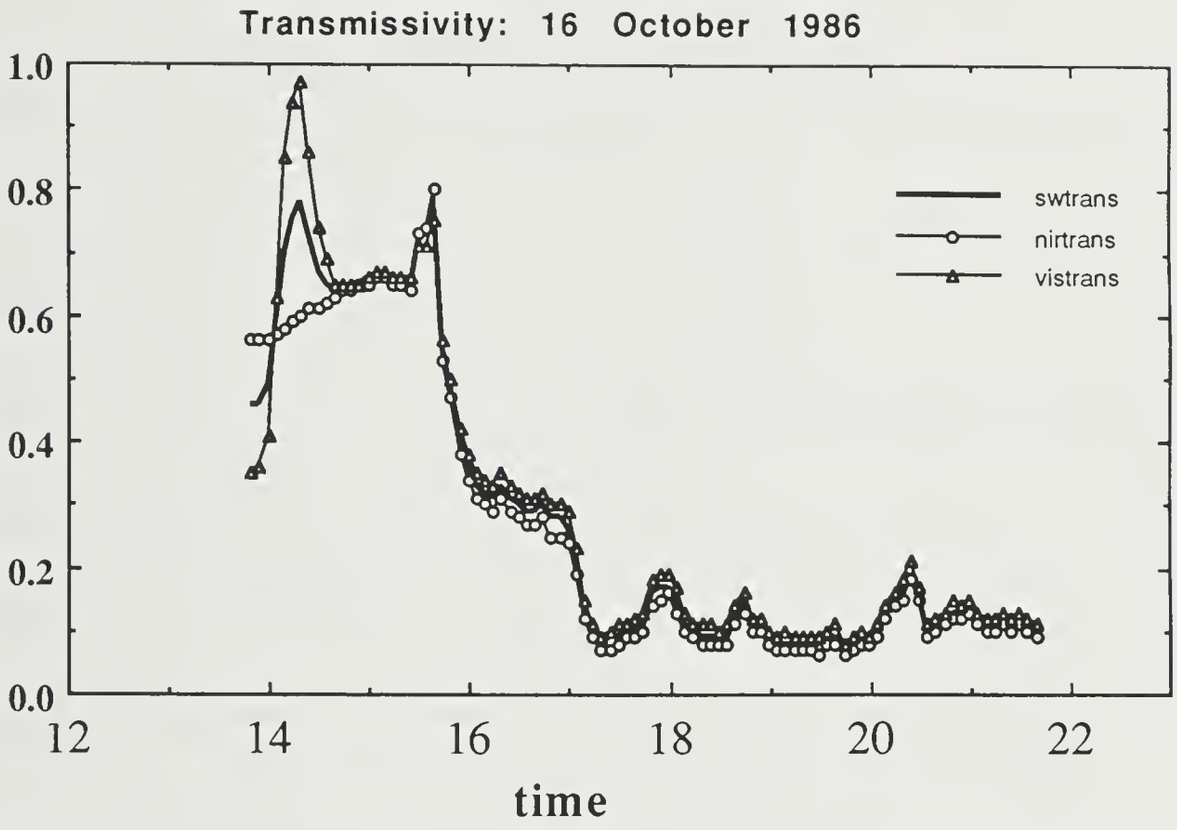
h) net surface irradiance (Oct. 19-31)

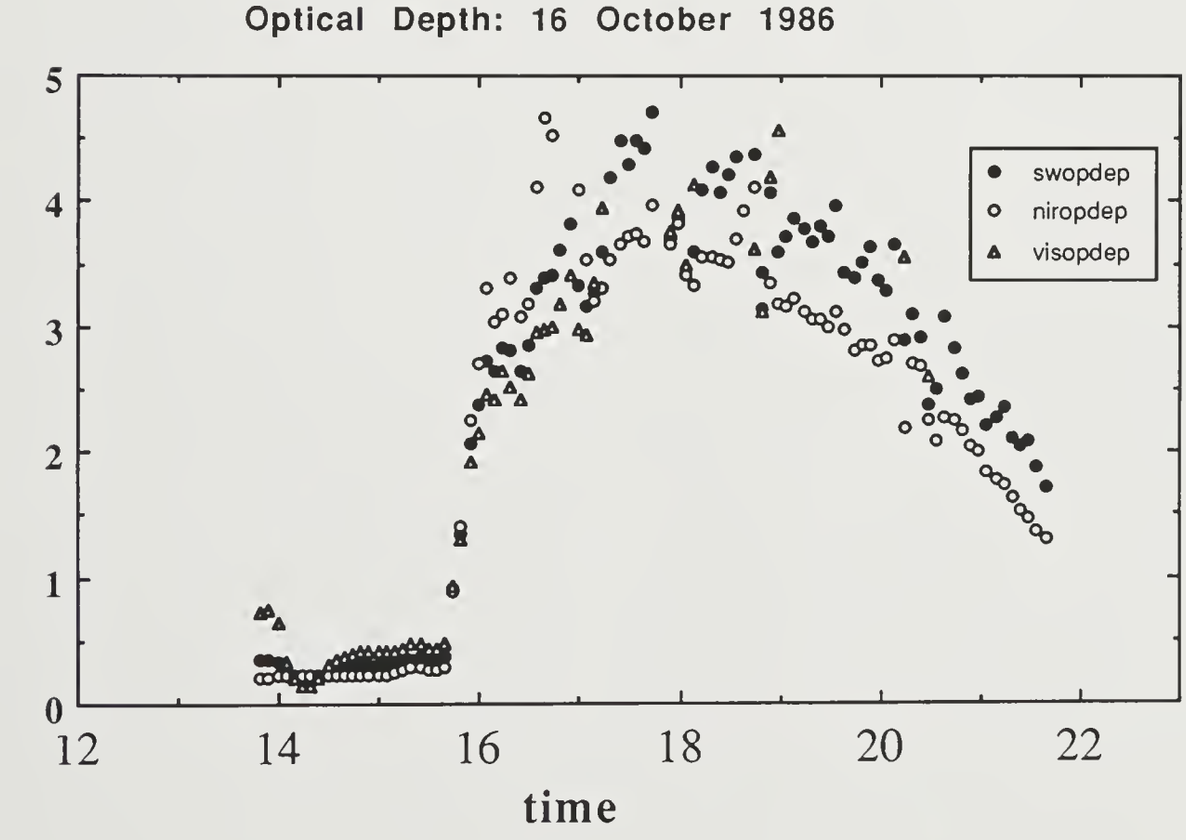

Full Irradiance: 16 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

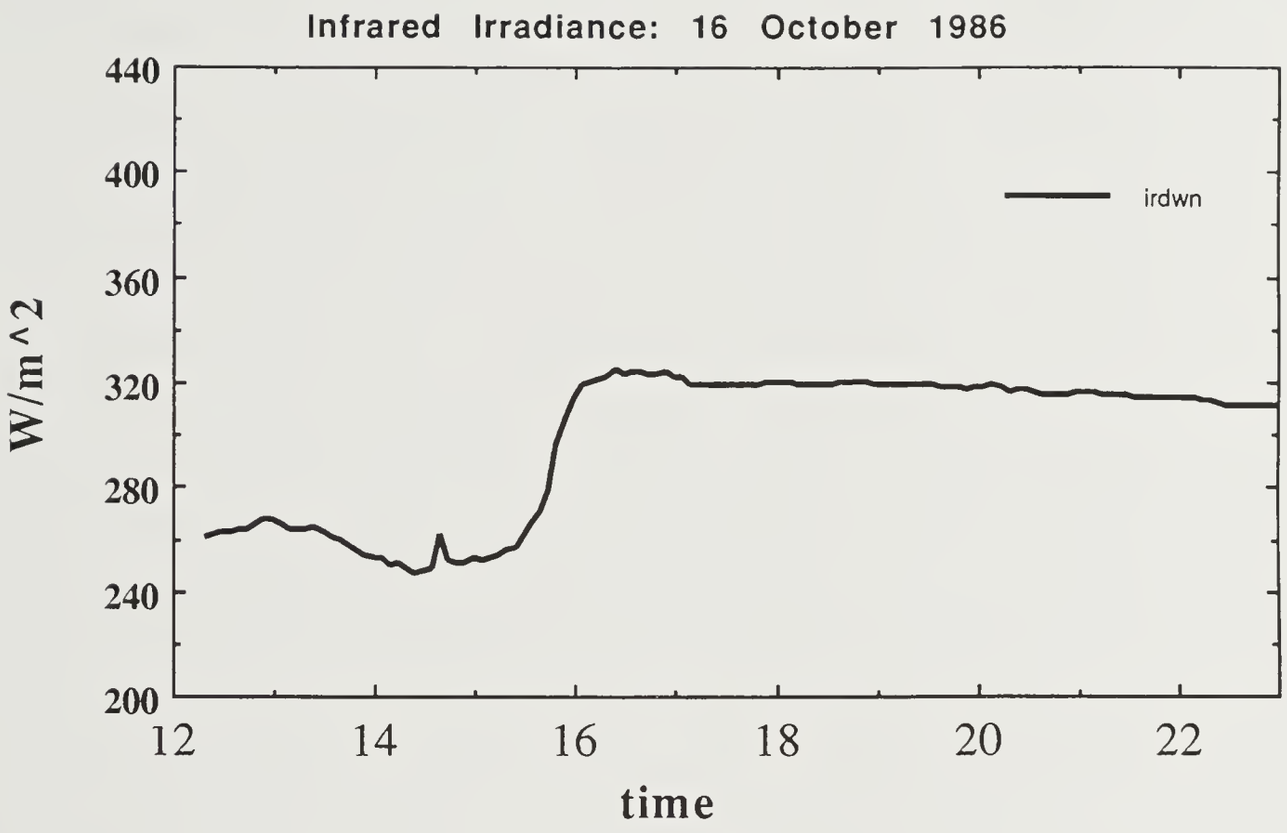

Diffuse Irradiation: 16 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd

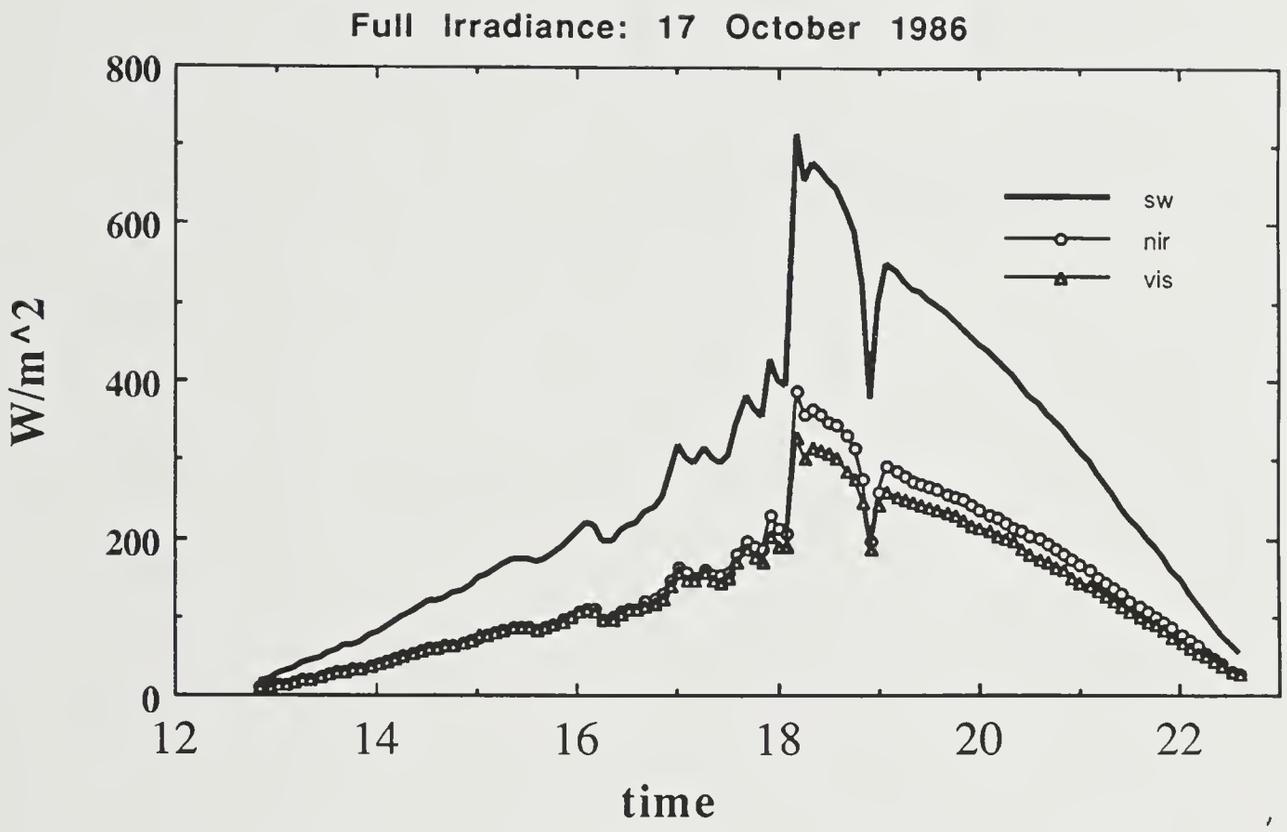

Ratio of NIR to VIS: 16 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time

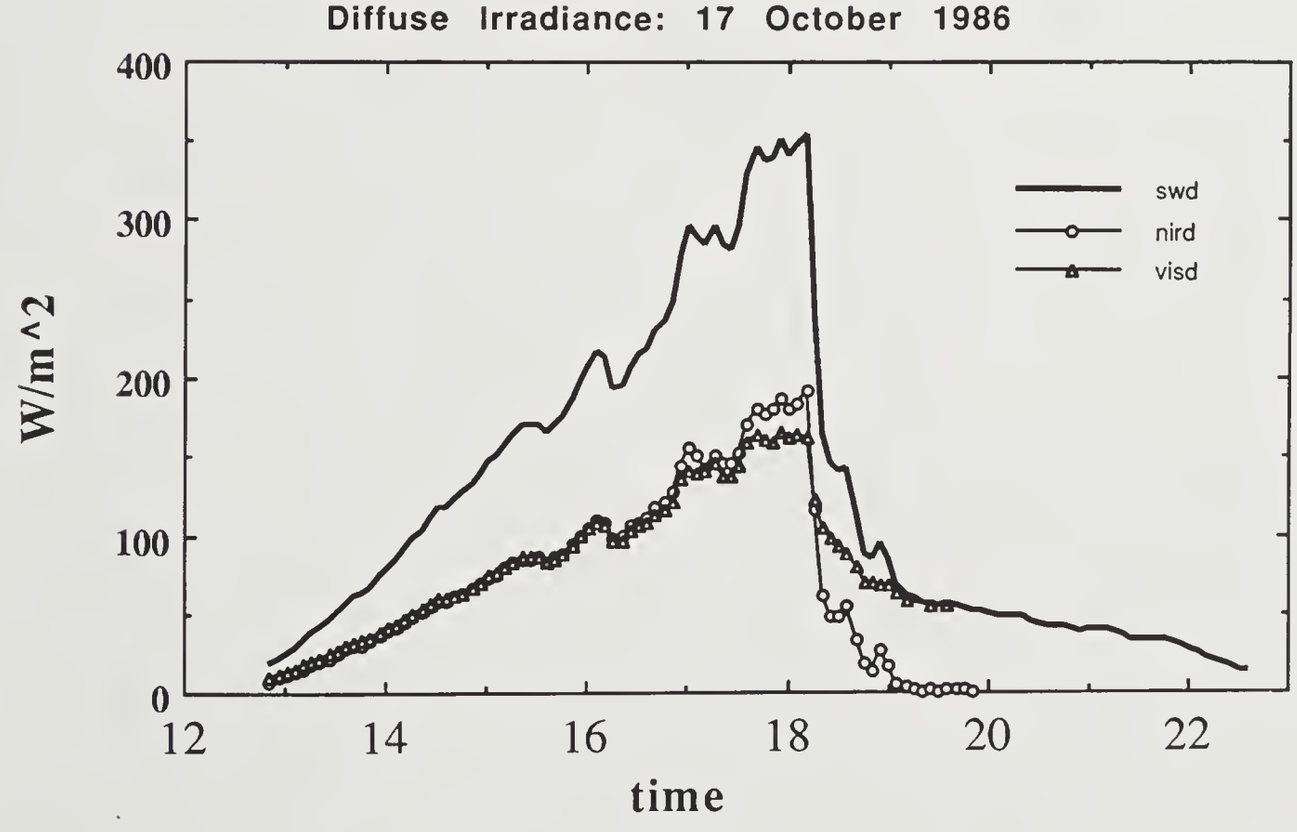

Fraction Diffuse Irradiance: 16 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swdfrac
nirdfrac
visdfrac

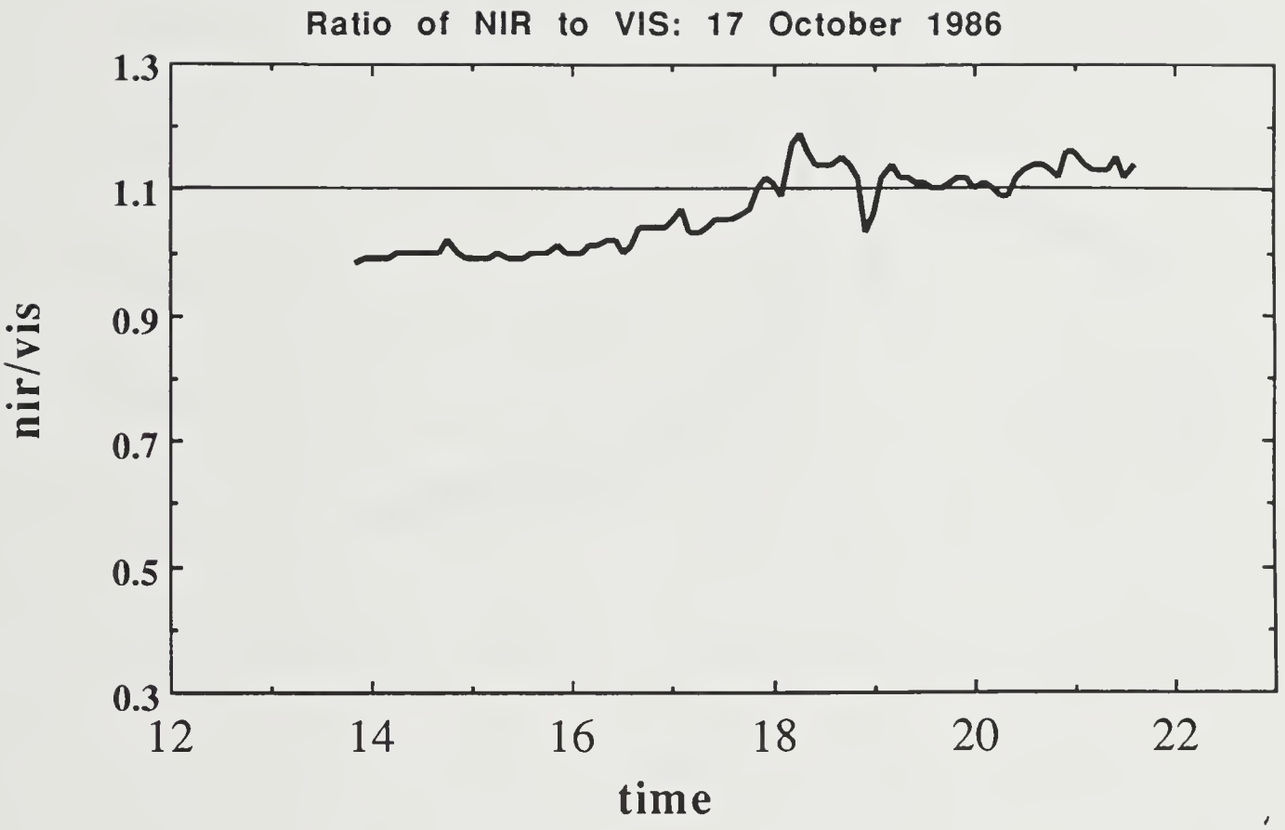

Transmissivity: 16 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

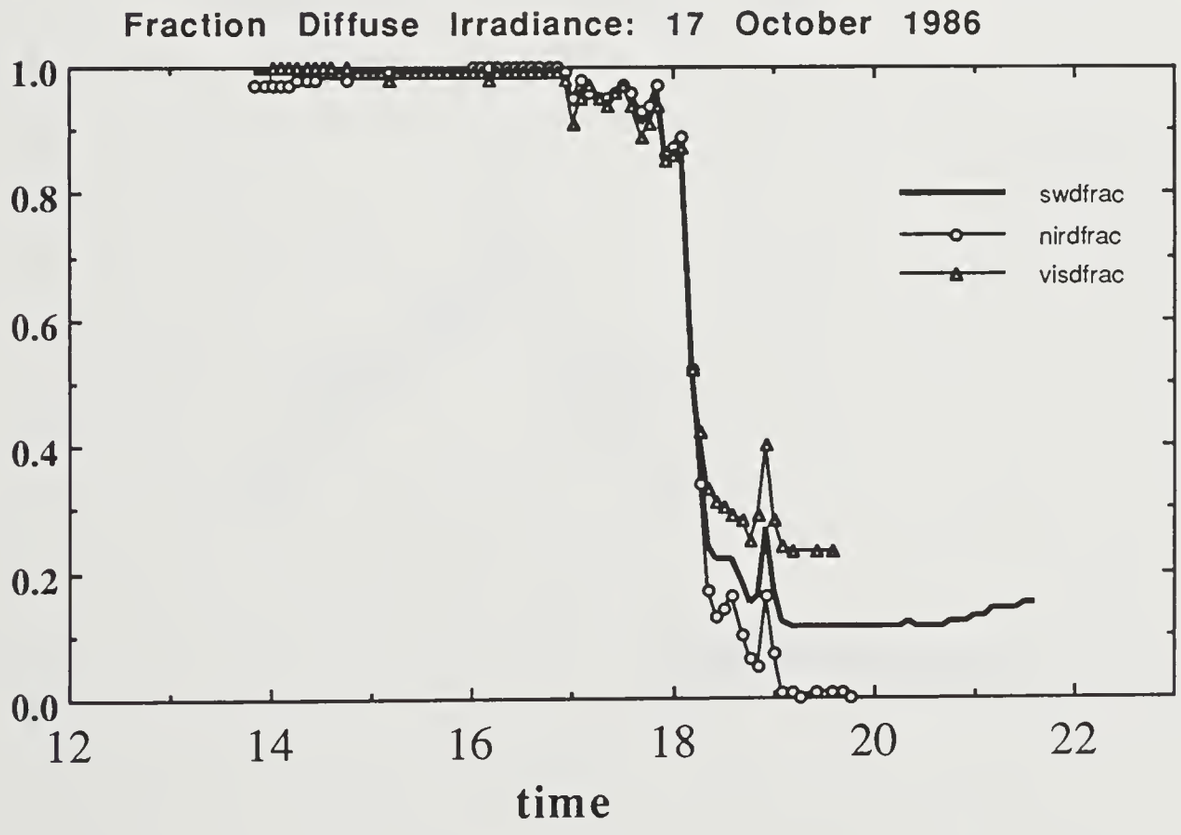

Optical Depth: 16 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep
niropdep
visopdep

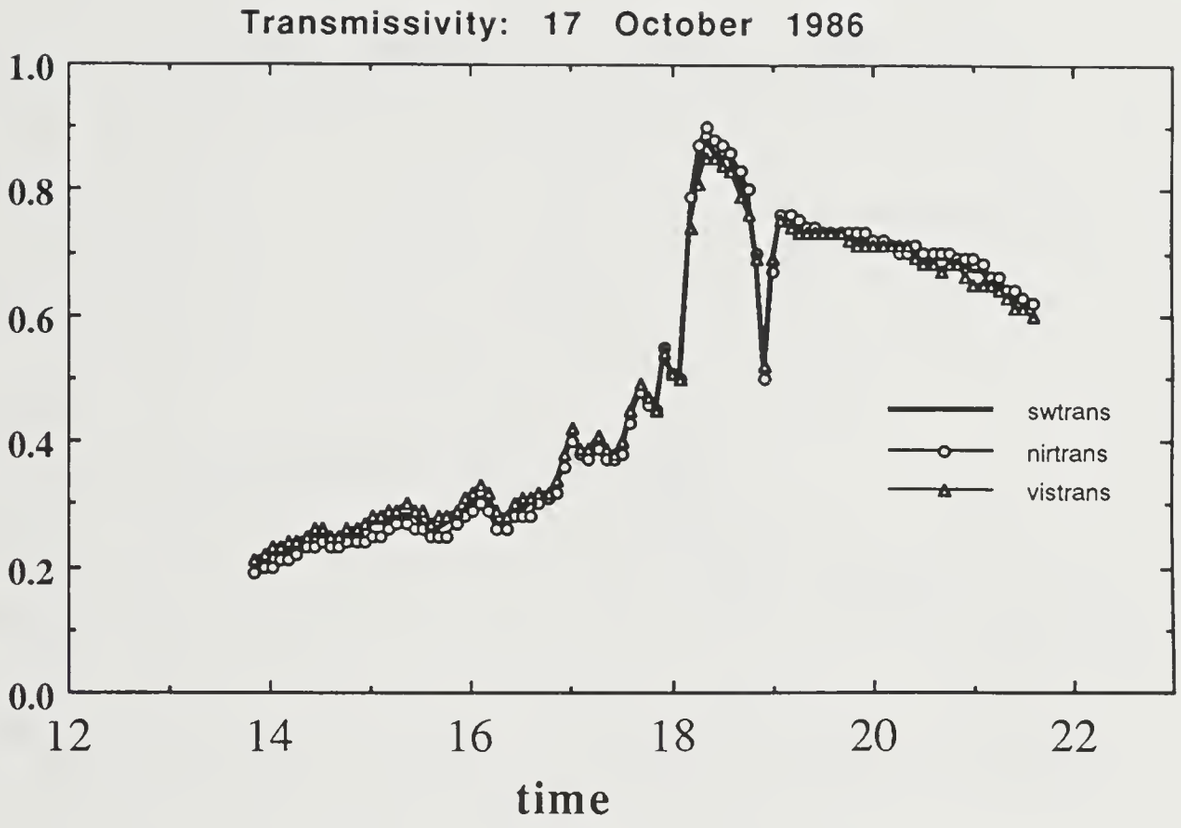

Infrared Irradiance: 16 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn

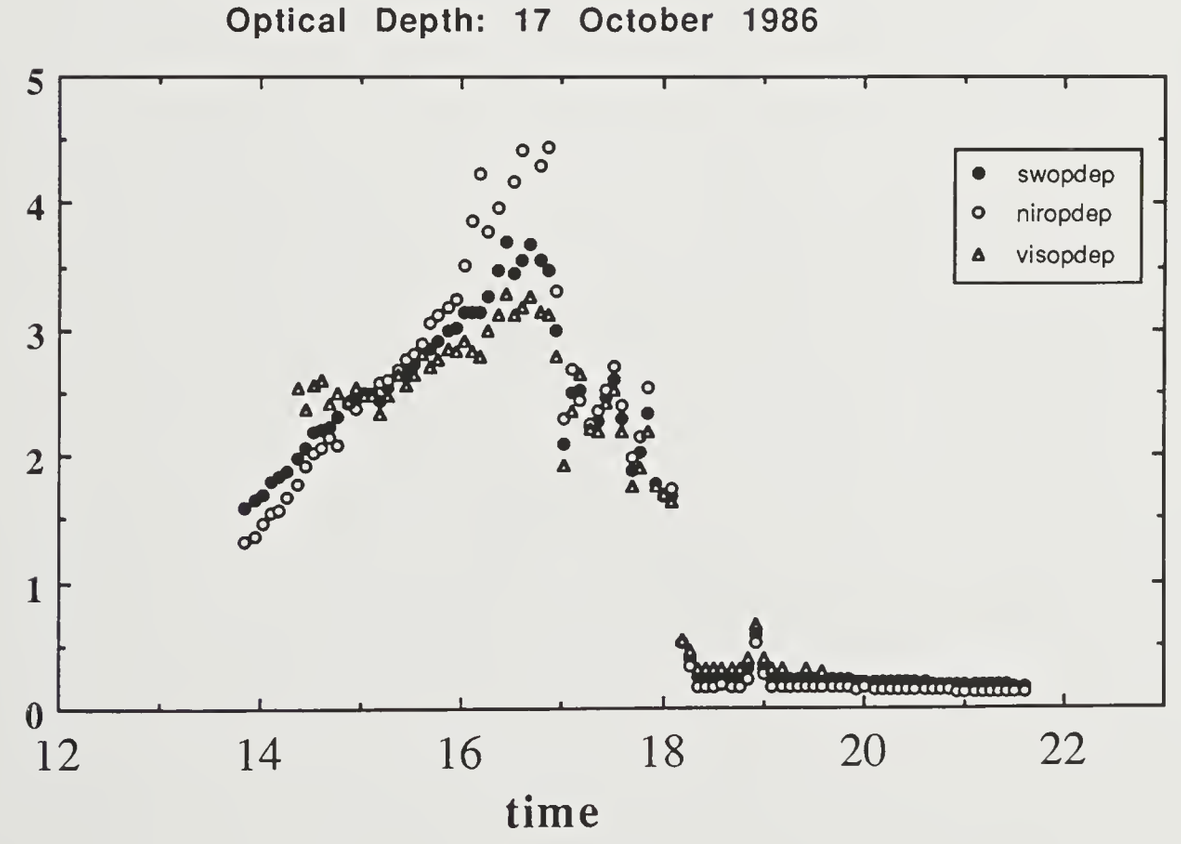

Full Irradiance: 17 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

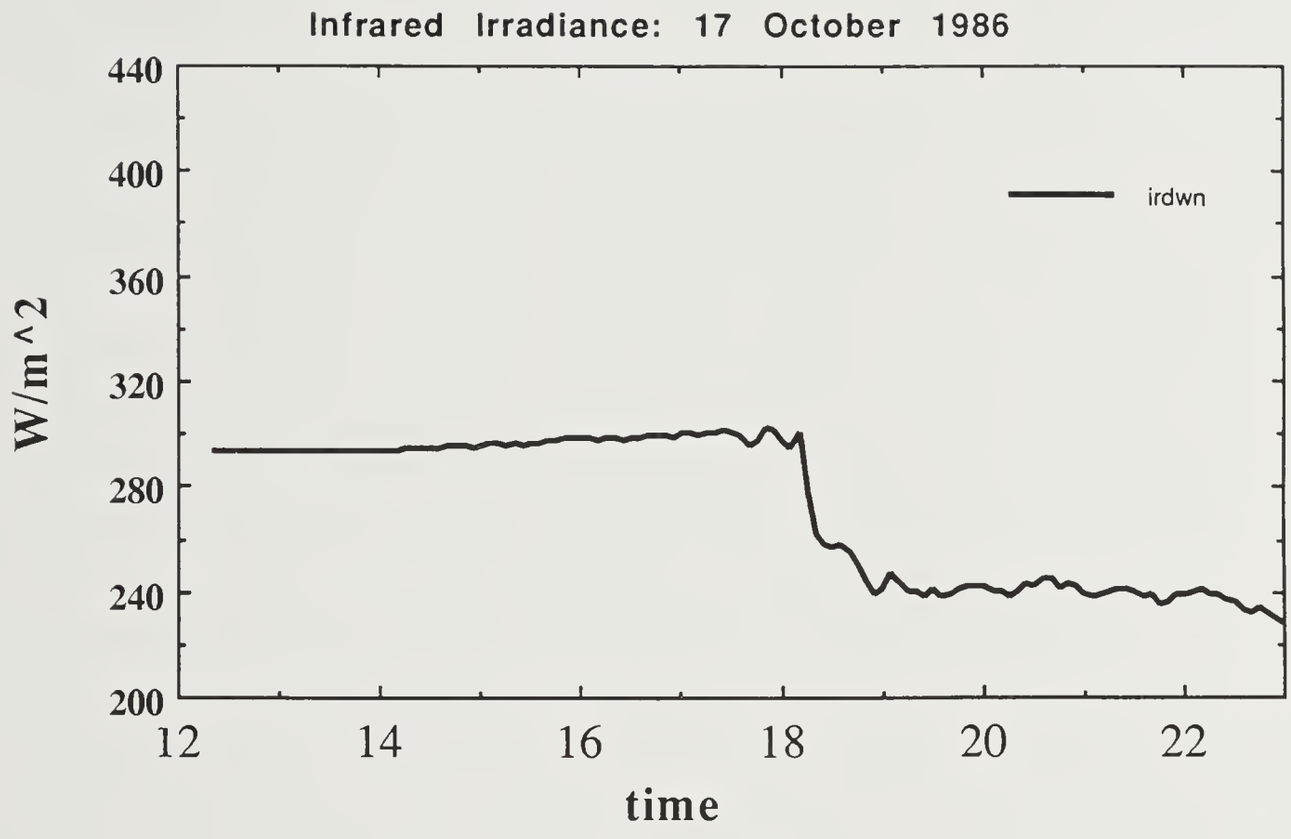

Diffuse Irradiance: 17 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd

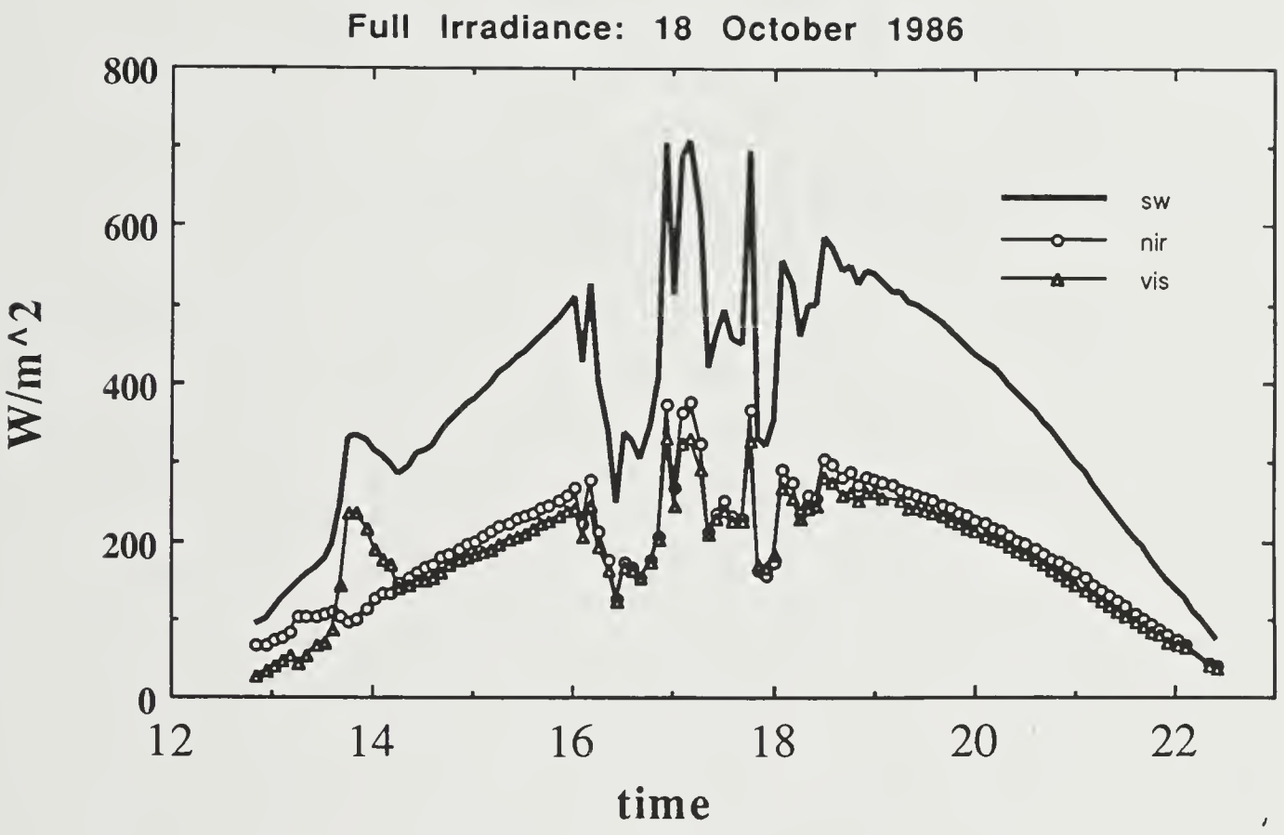

Ratio of NIR to VIS: 17 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time

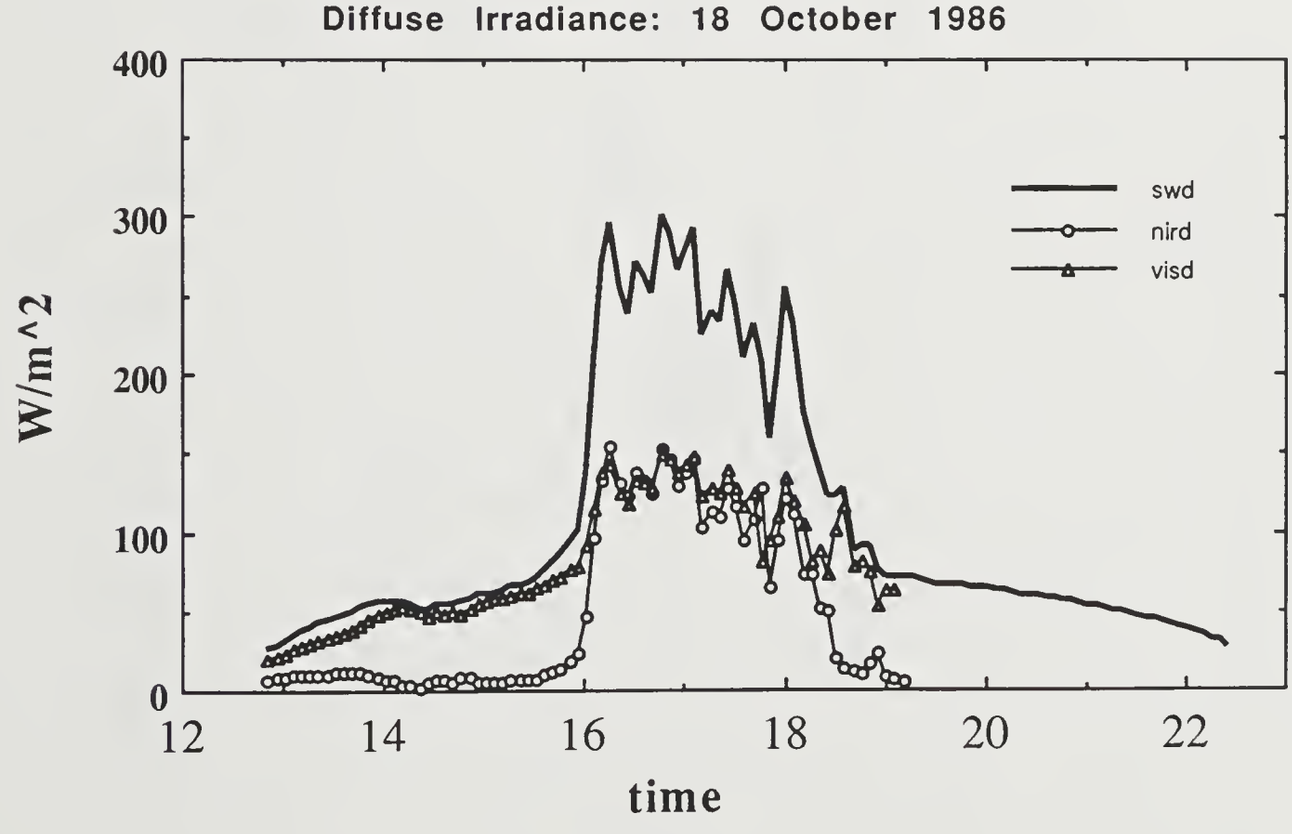

Fraction Diffuse Irradiance: 17 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swdfrac
nirdfrac
visdfrac

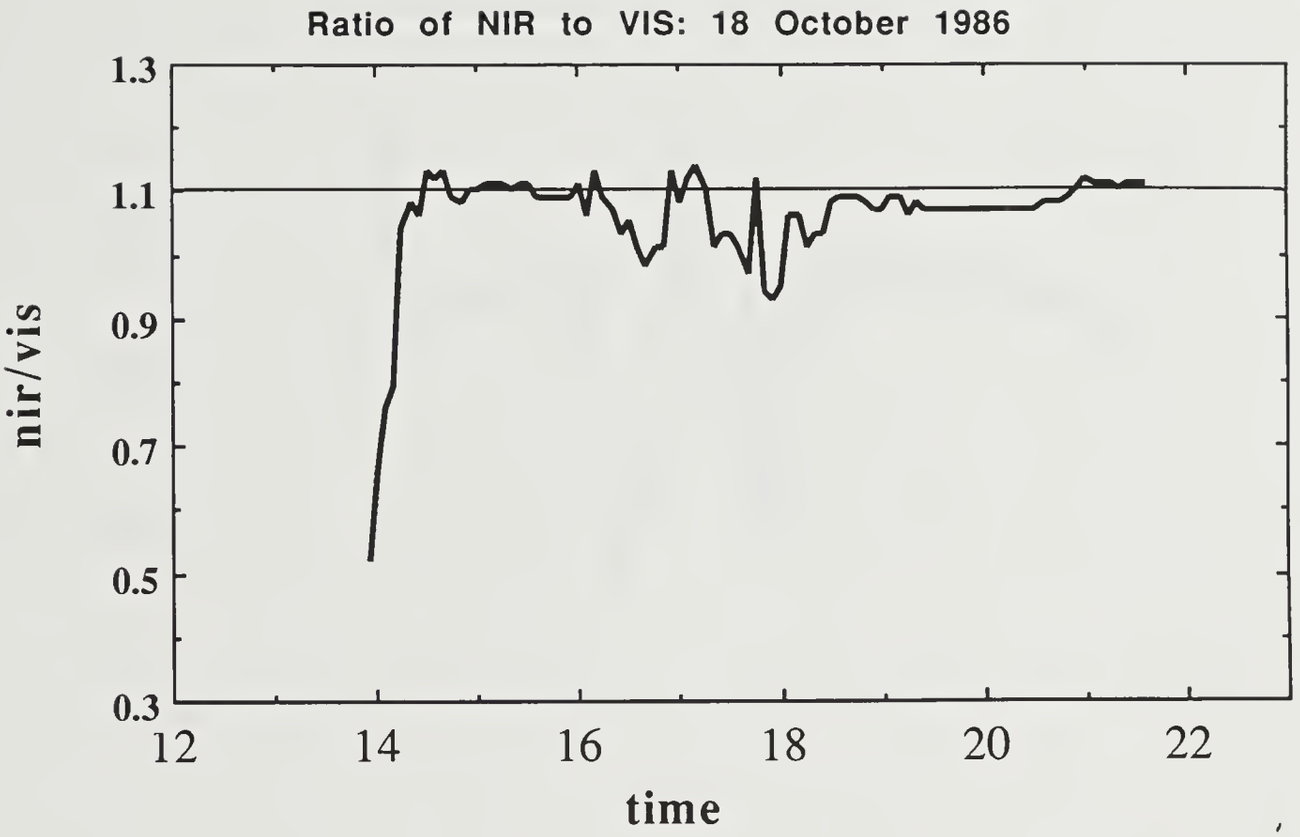

Transmissivity: 17 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

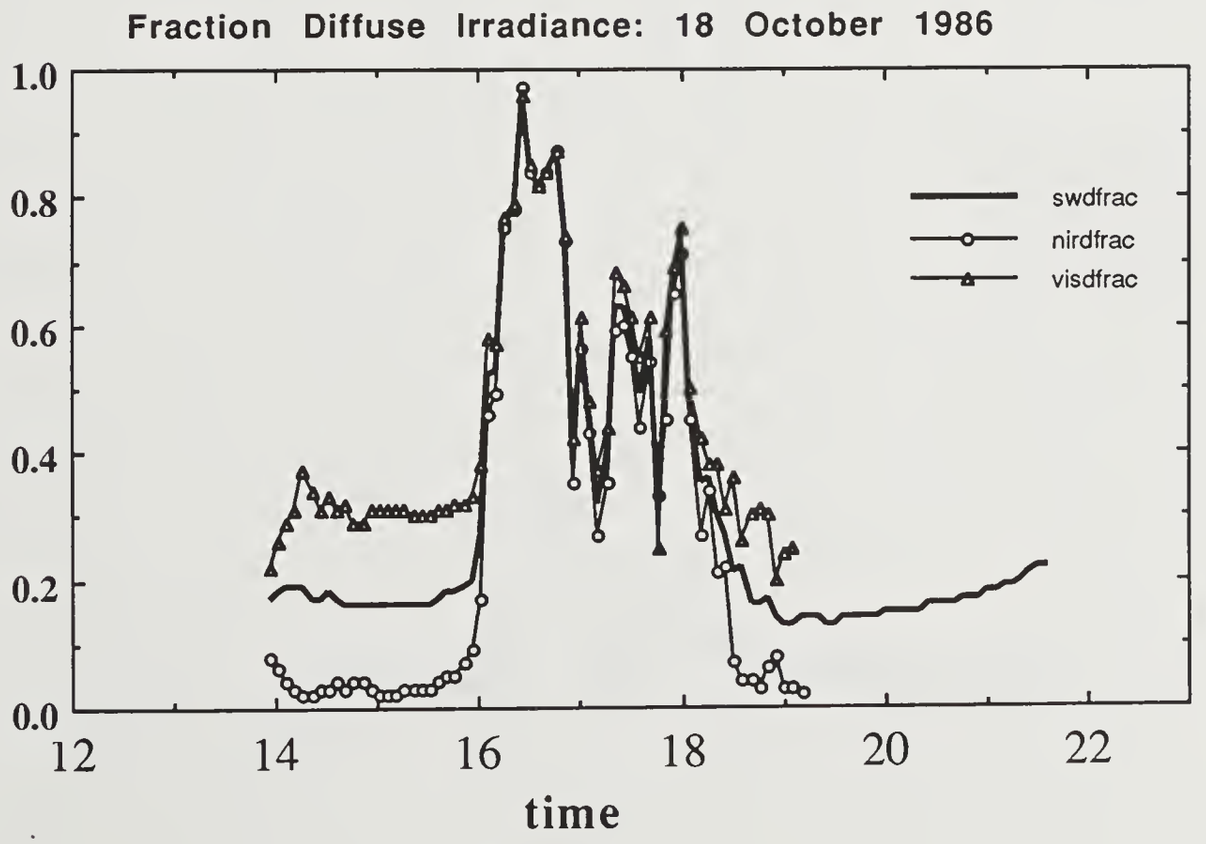

Optical Depth: 17 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep
niropdep
visopdep

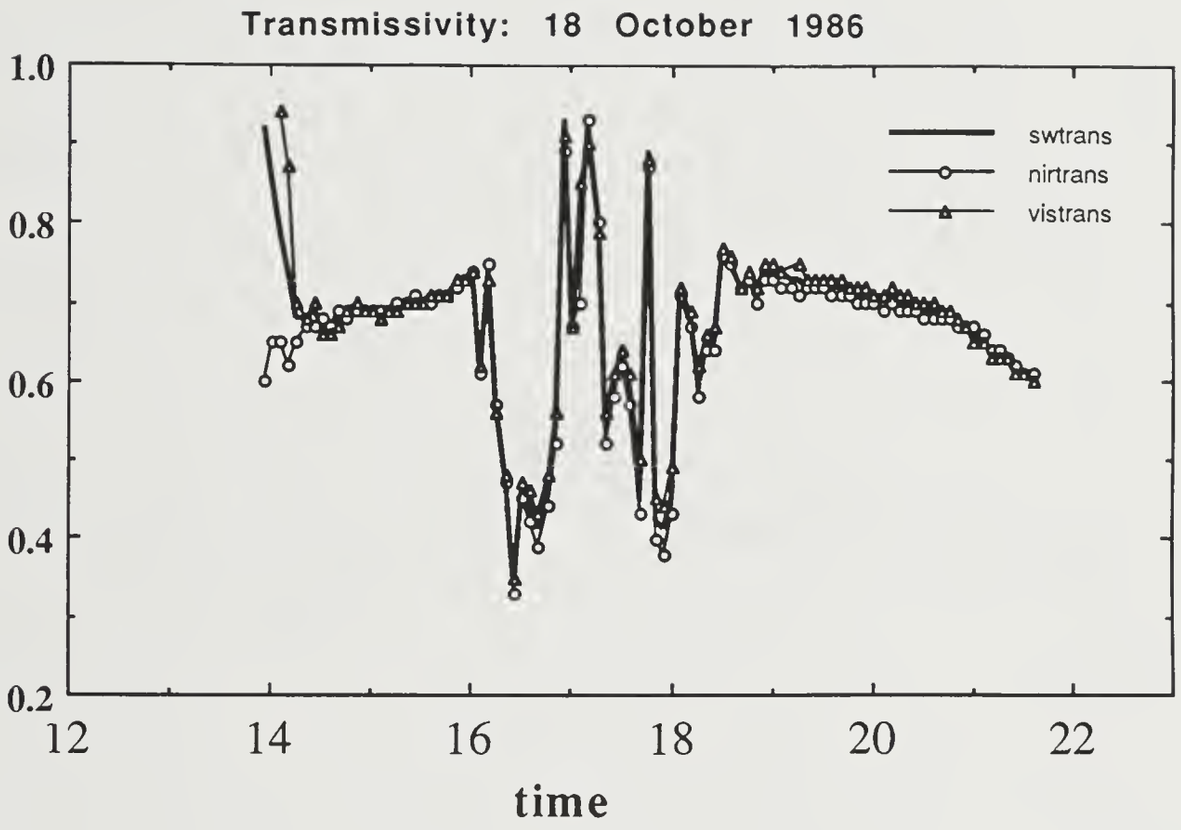

Infrared Irradiance: 17 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn

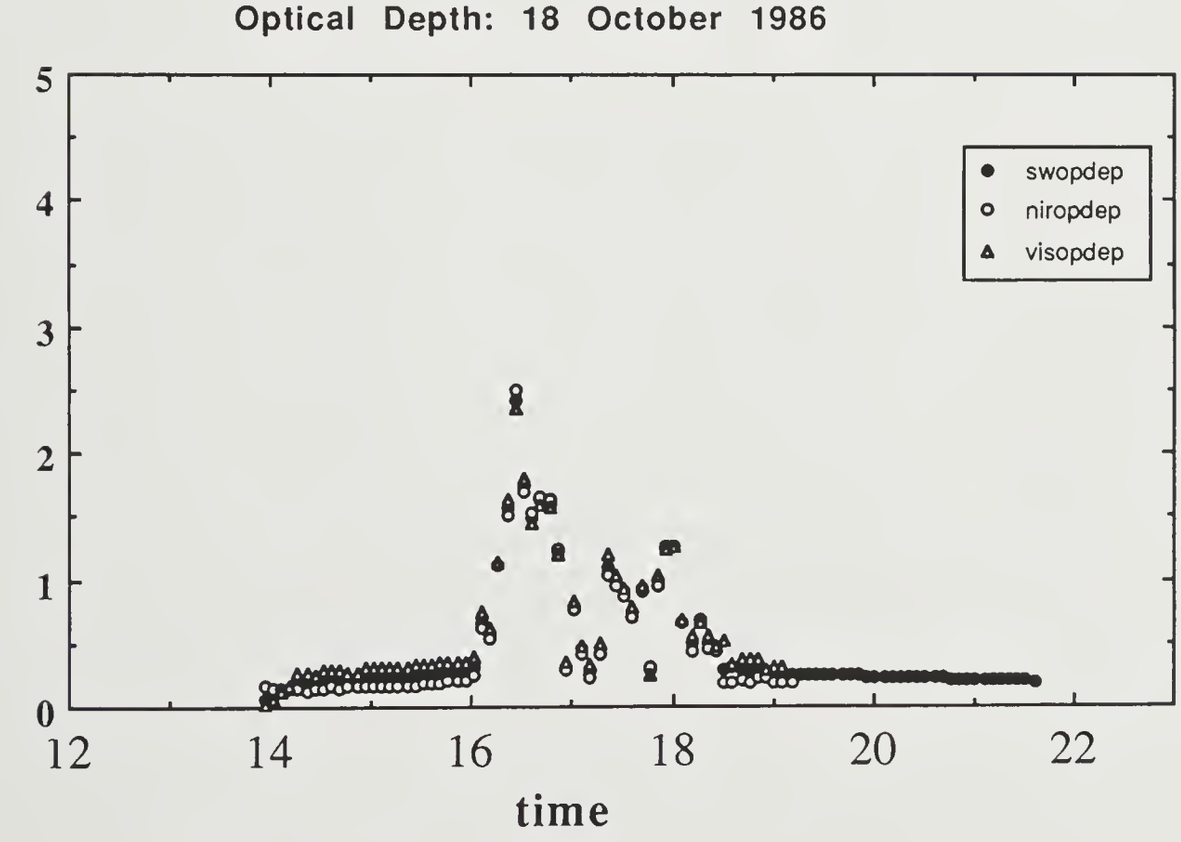

Full Irradiance: 18 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

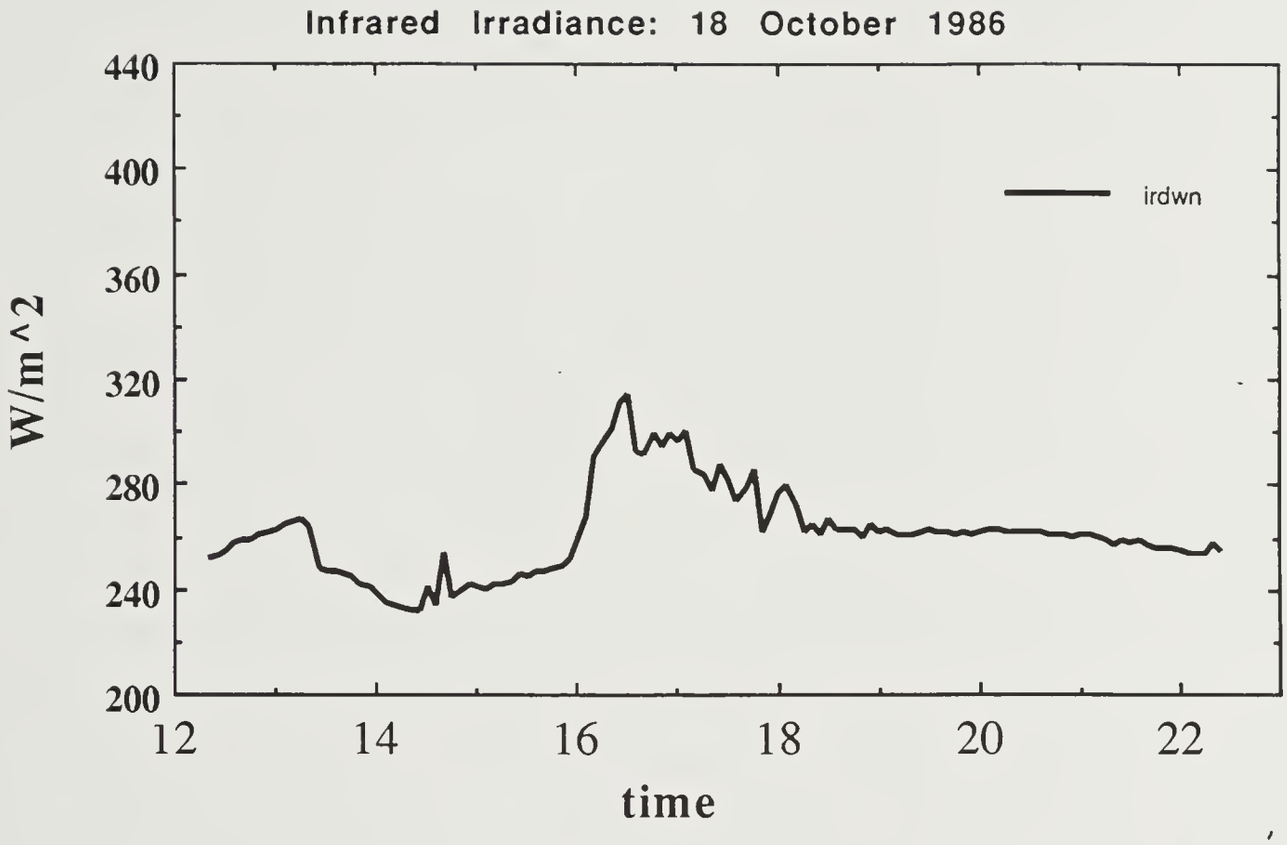

Diffuse Irradiance: 18 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd

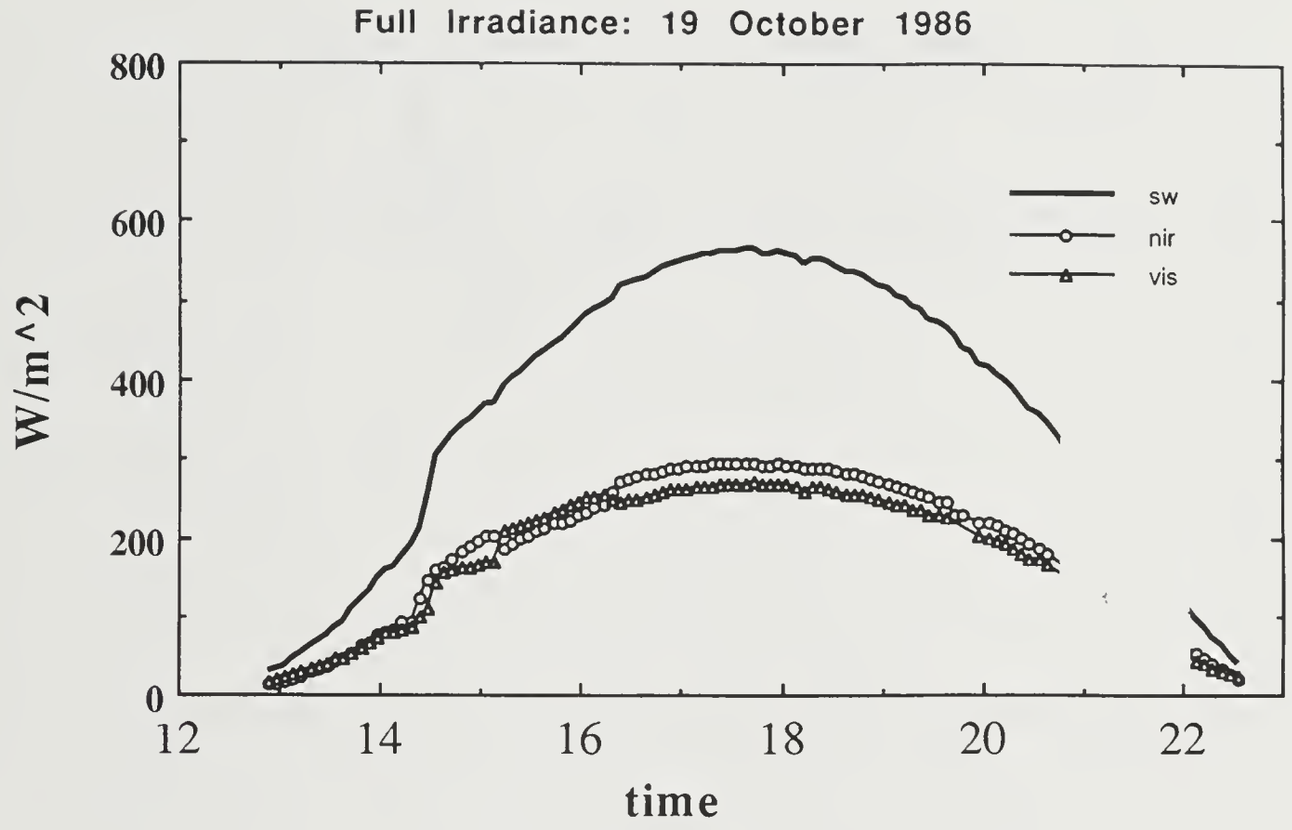

Ratio of NIR to VIS: 18 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time

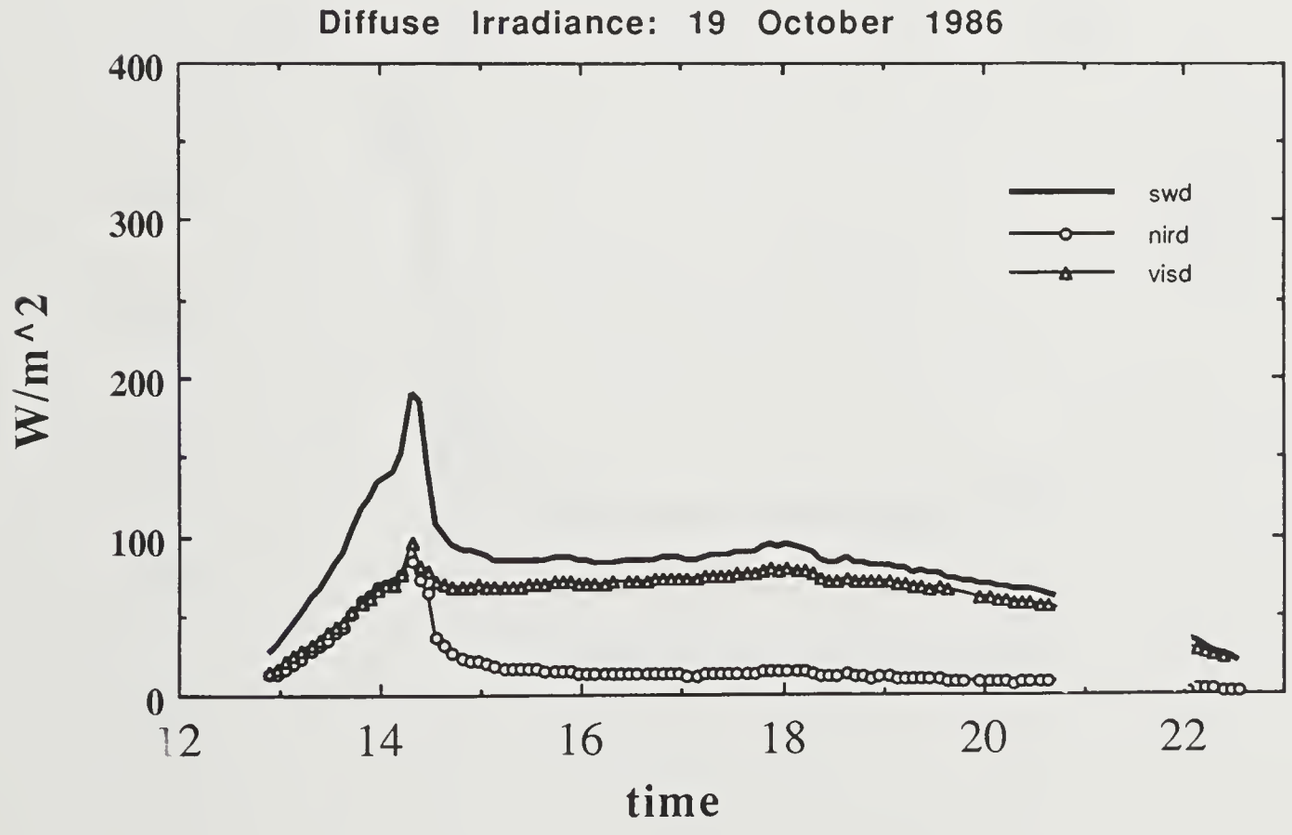

Fraction Diffuse Irradiance: 18 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swdfrac
nirdfrac
visdfrac

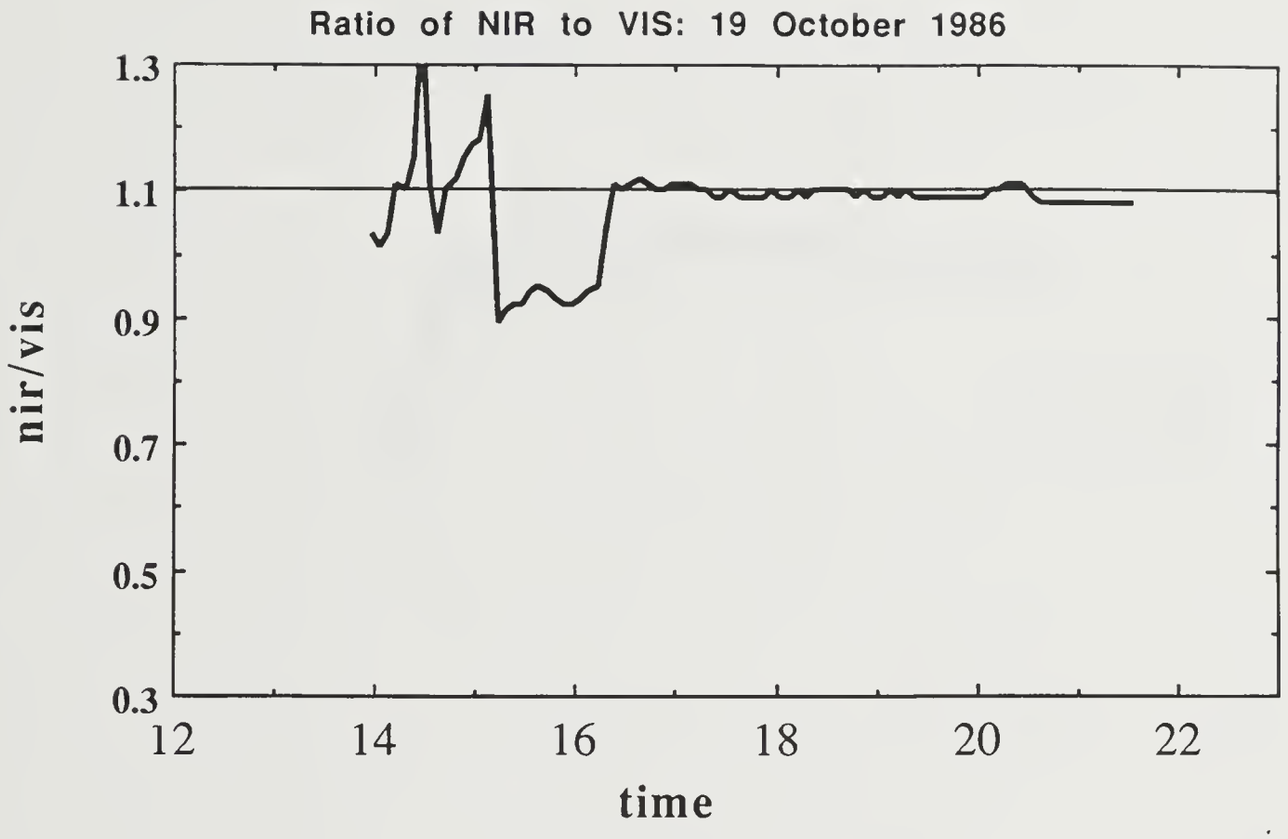

Transmissivity: 18 October 1986
1.0
0.8
0.6
0.4
0.2
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

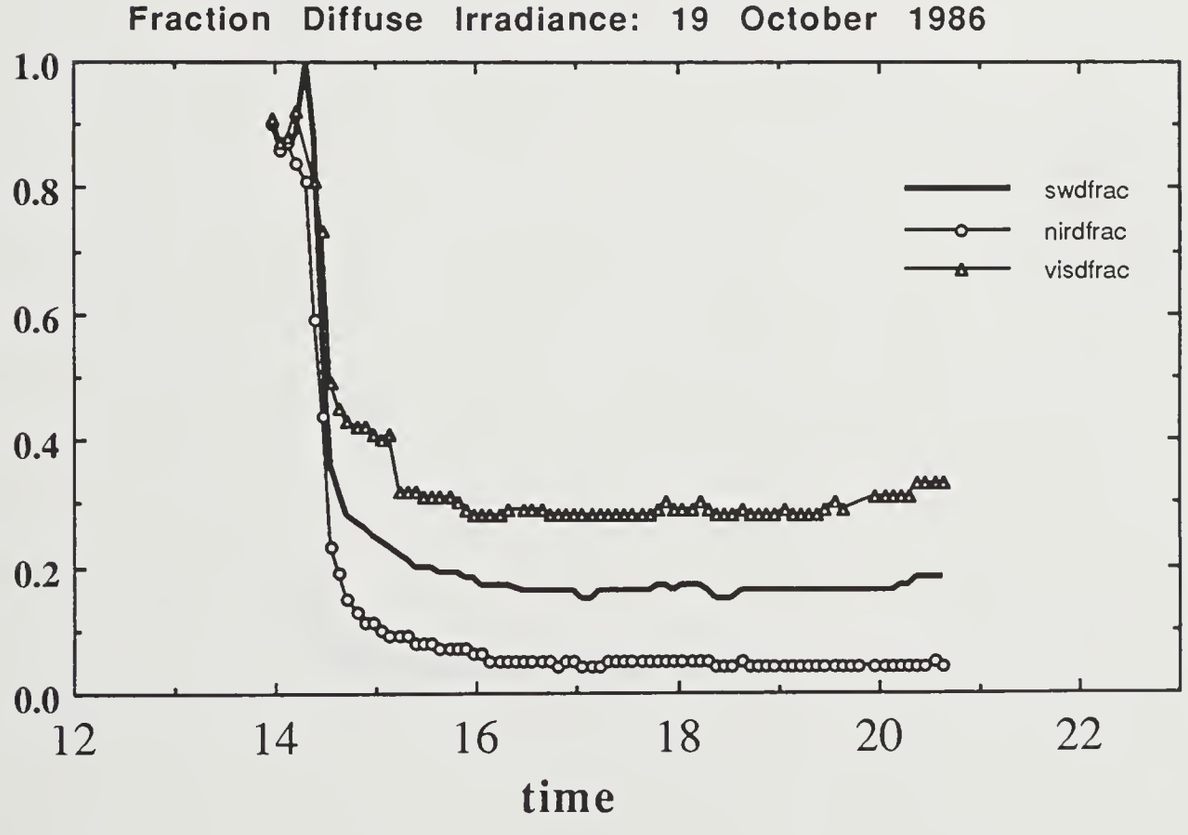

Optical Depth: 18 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep
niropdep
visopdep

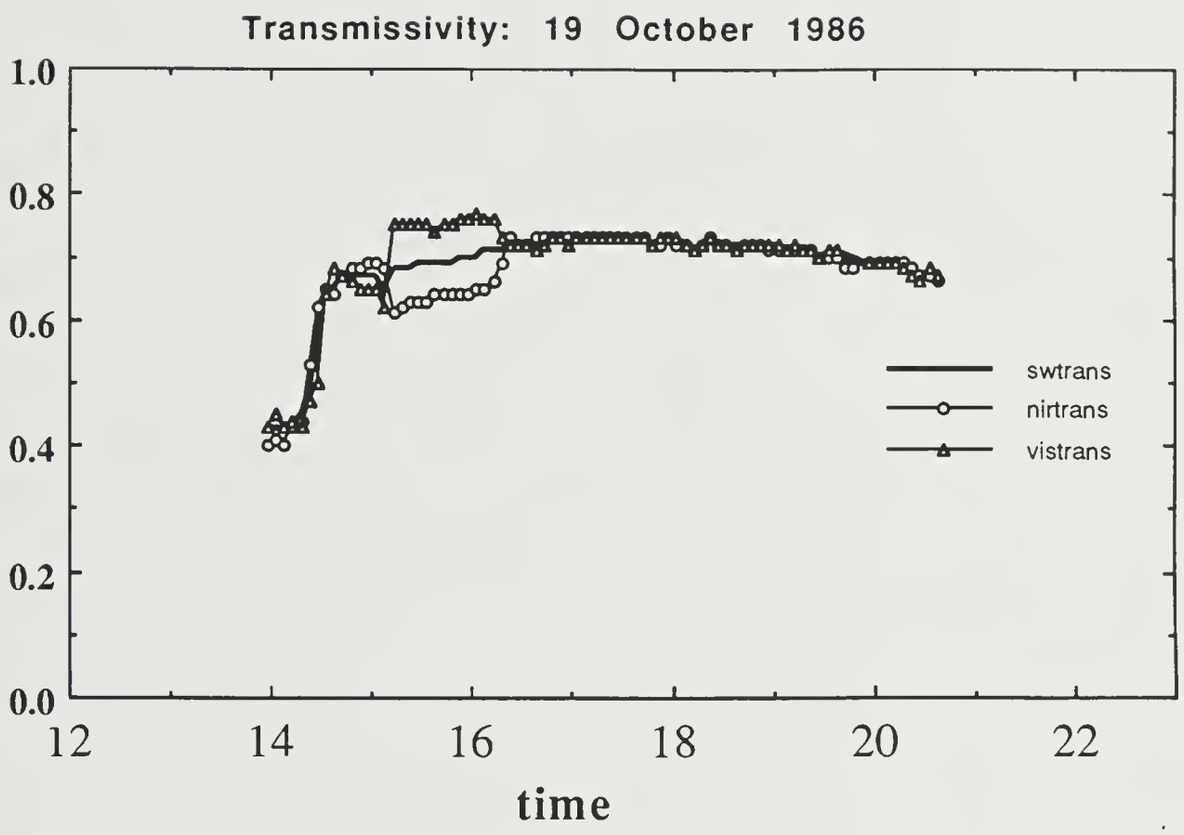

Infrared Irradiance: 18 October 1986
440
400
360
320
280
240
200
W/m^2
irdwn
12
14
16
18
20
22
time

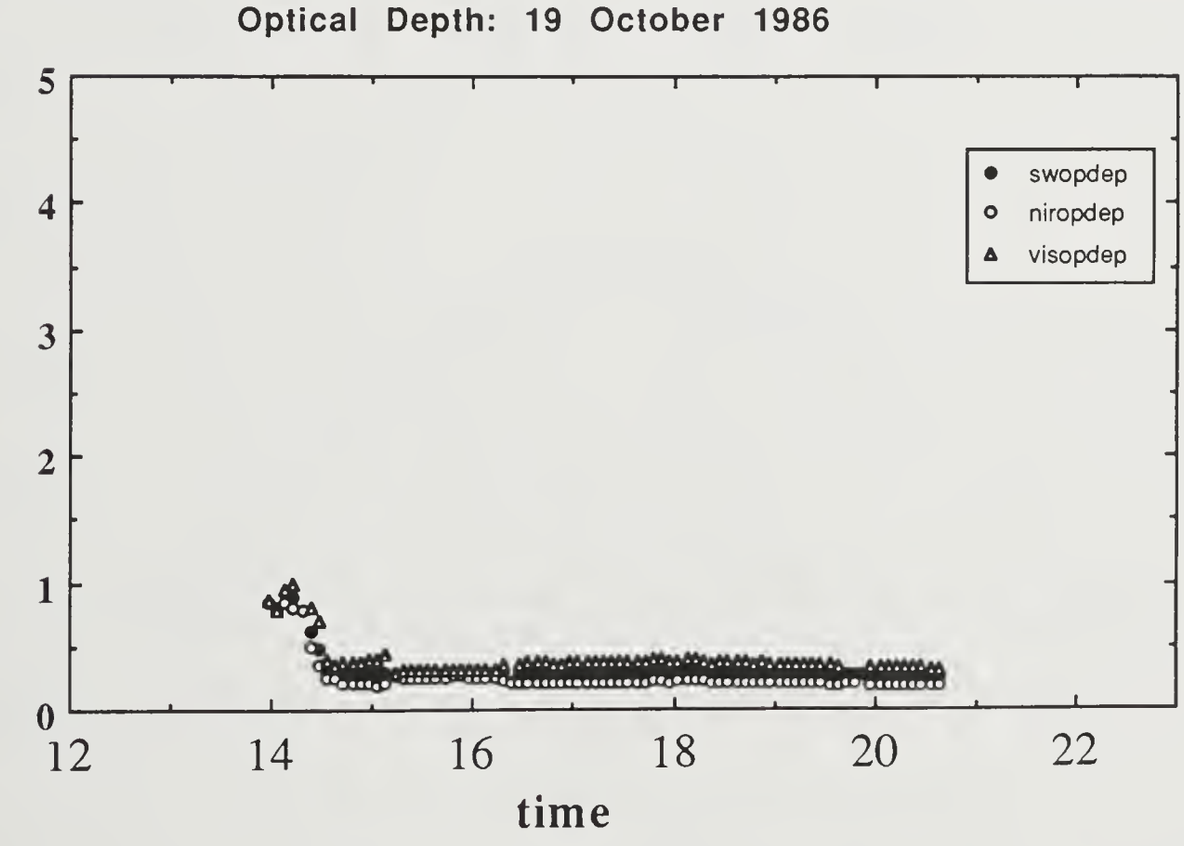

Full Irradiance: 19 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

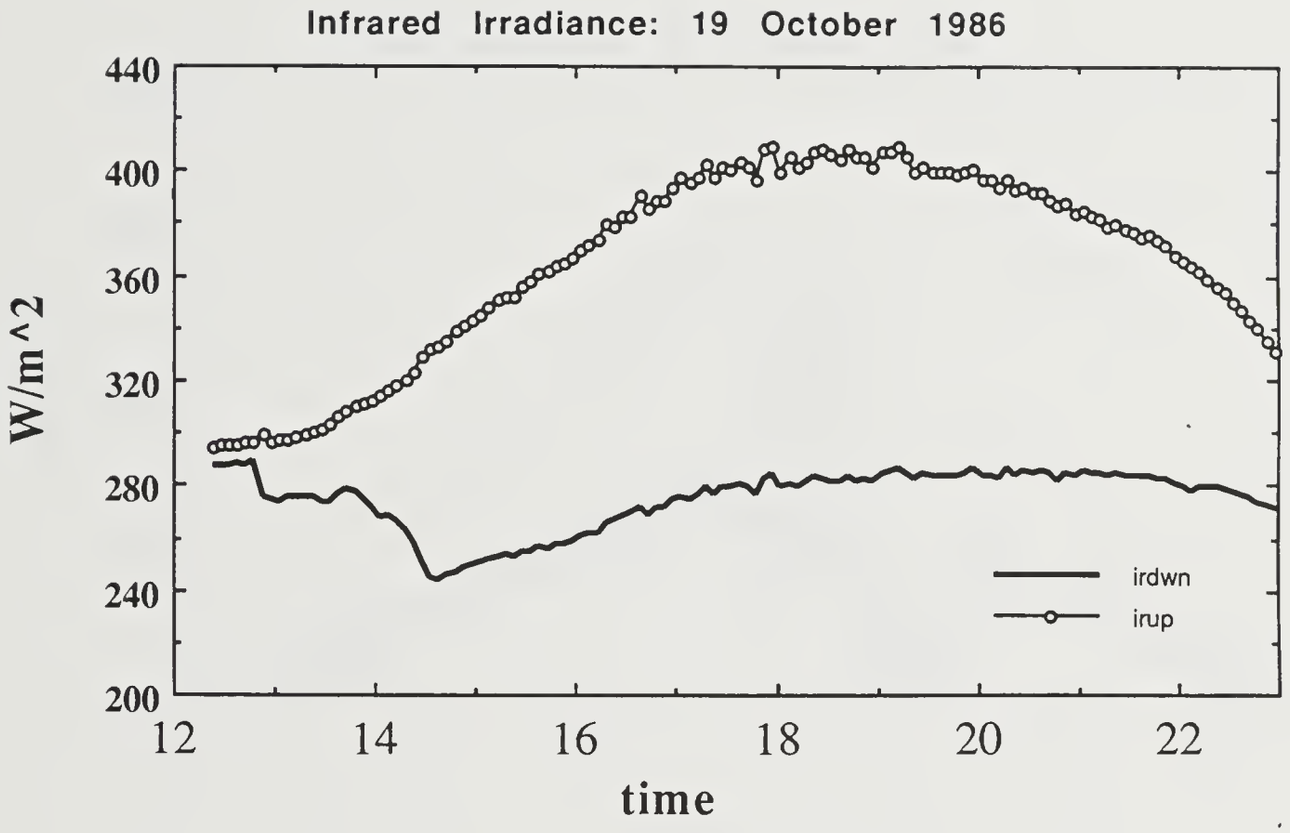

Diffuse Irradiance: 19 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd

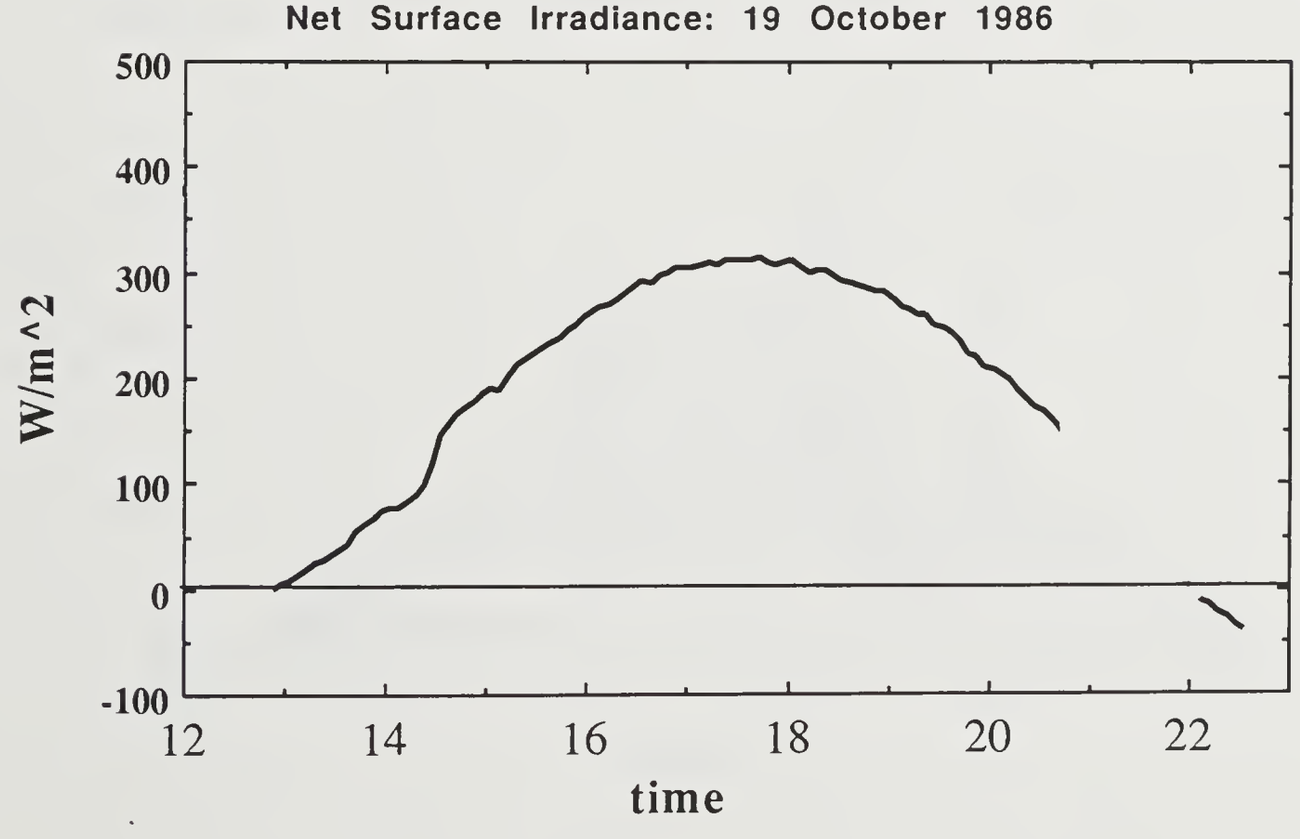

Ratio of NIR to VIS: 19 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time

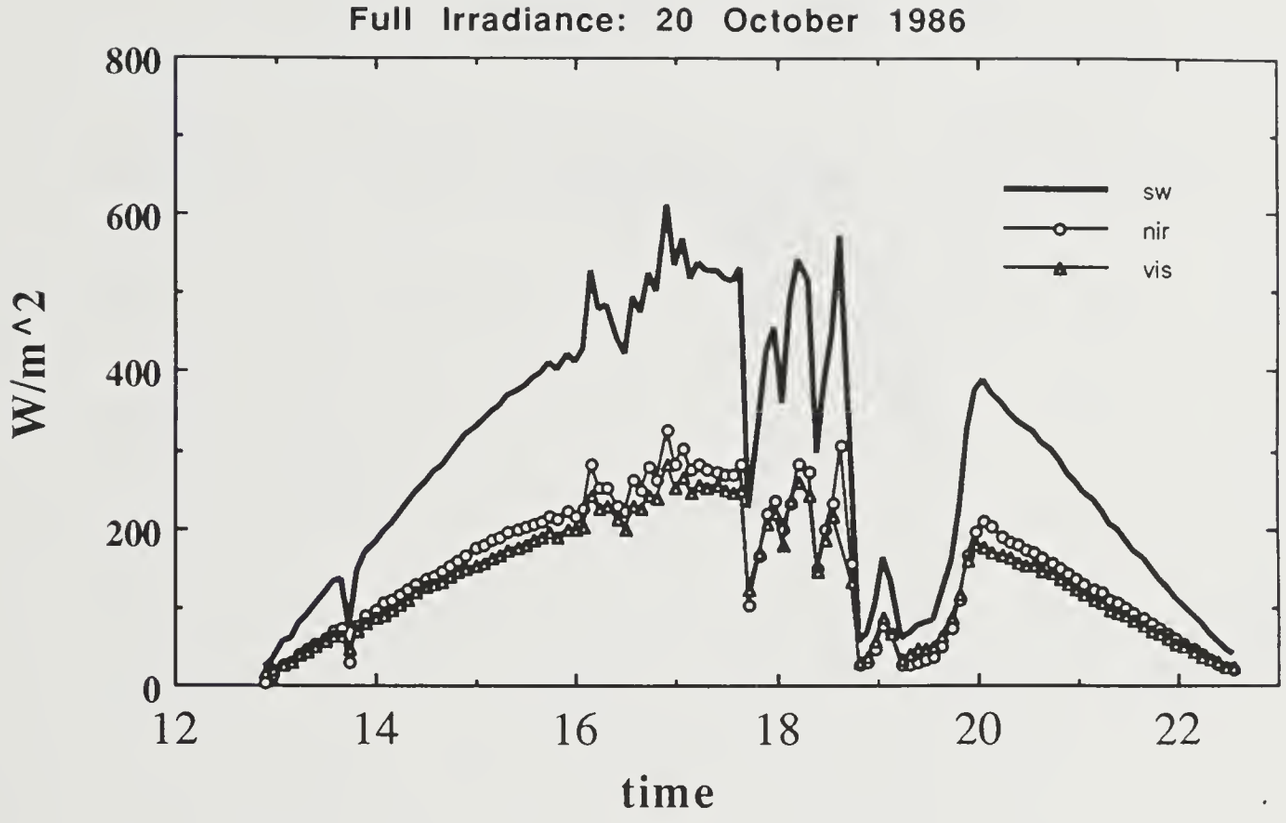

Fraction Diffuse Irradiance: 19 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swdfrac
nirdfrac
visdfrac

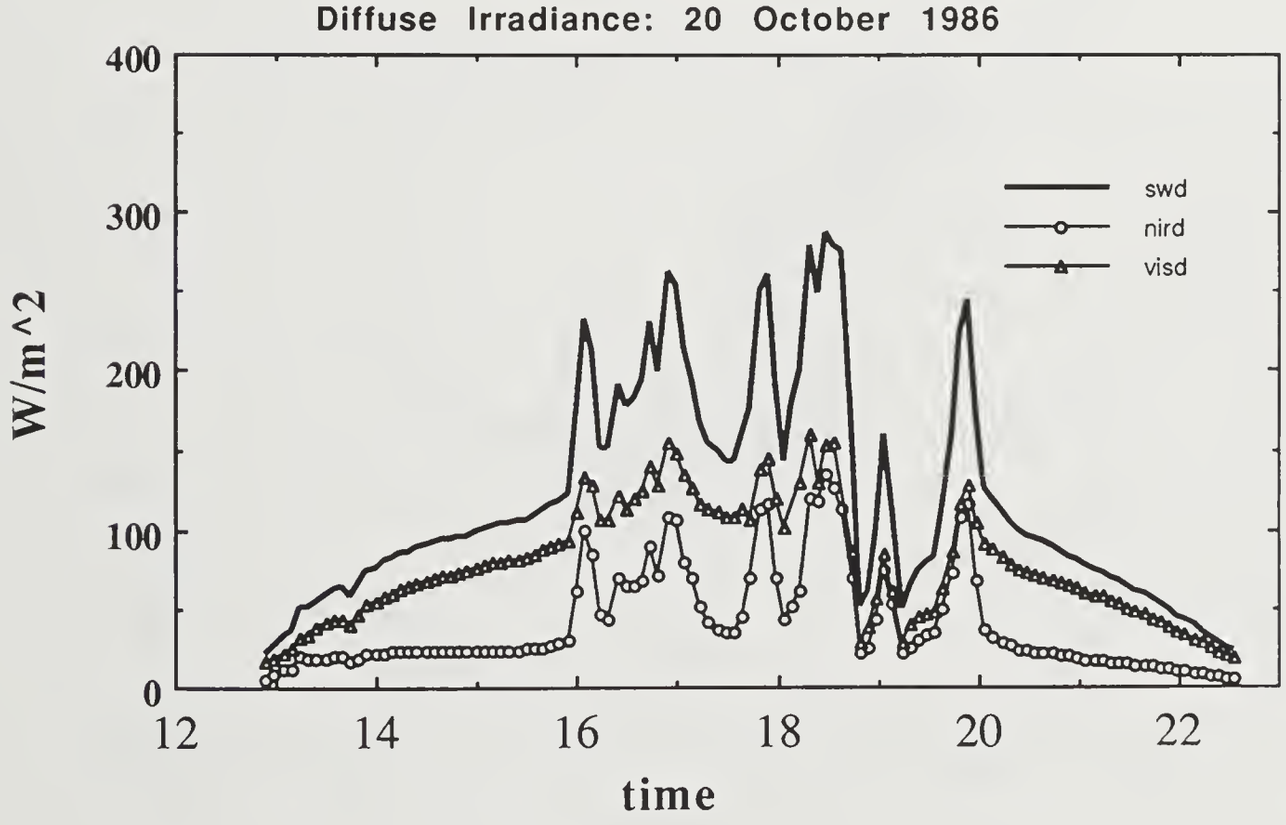

Transmissivity: 19 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

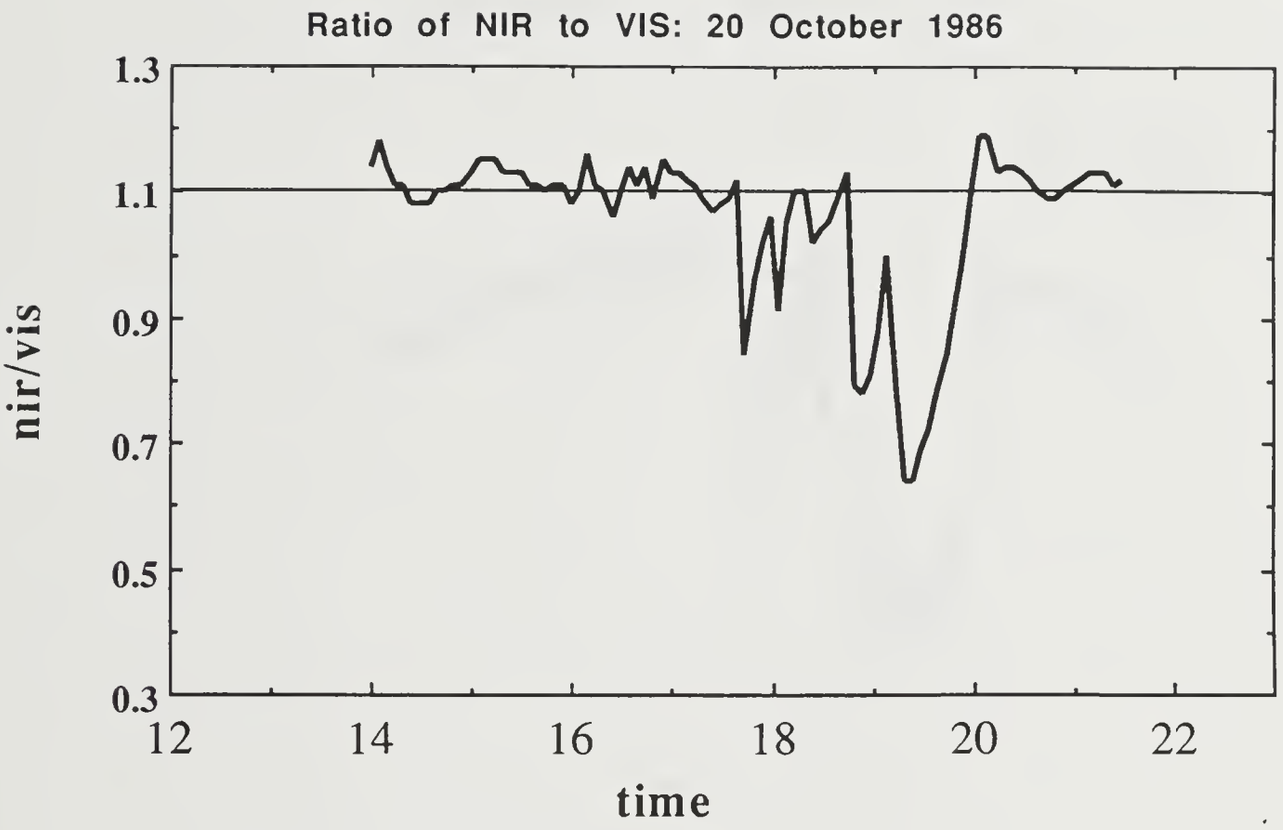

Optical Depth: 19 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep
niropdep
visopdep

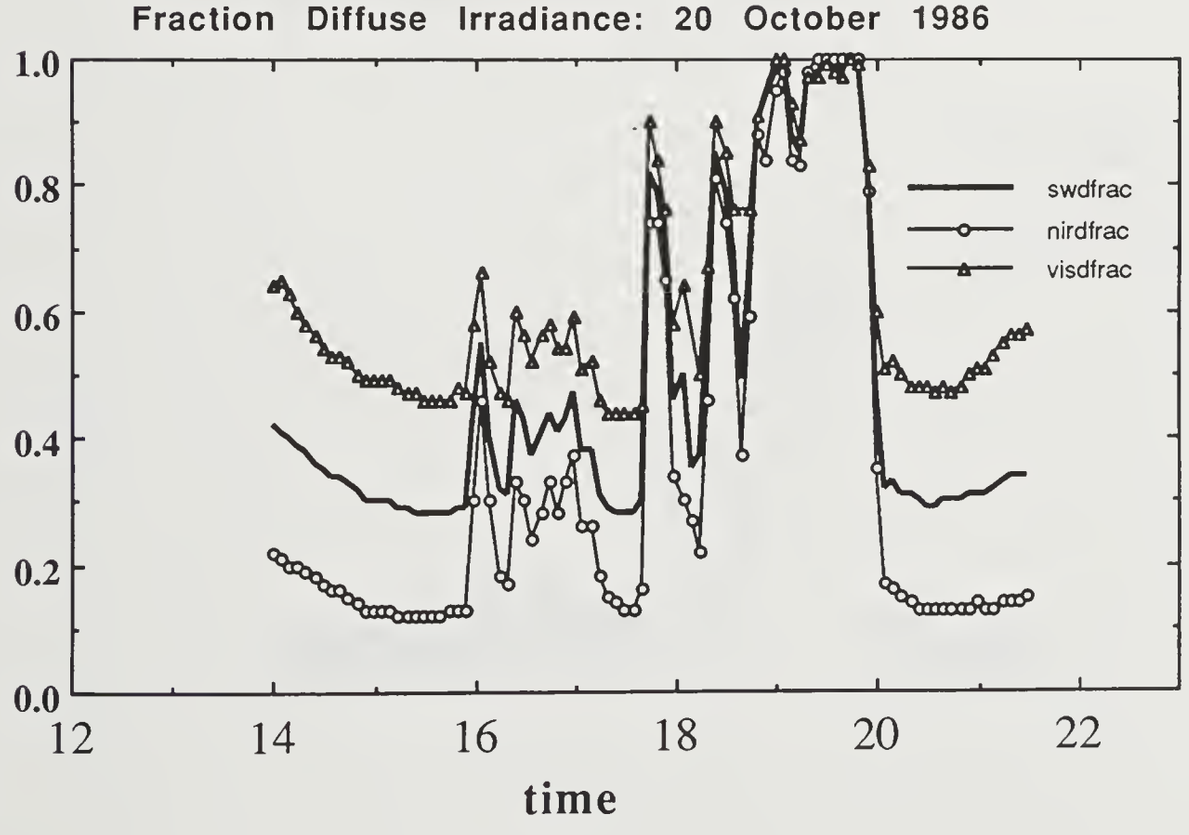

Infrared Irradiance: 19 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn
irup

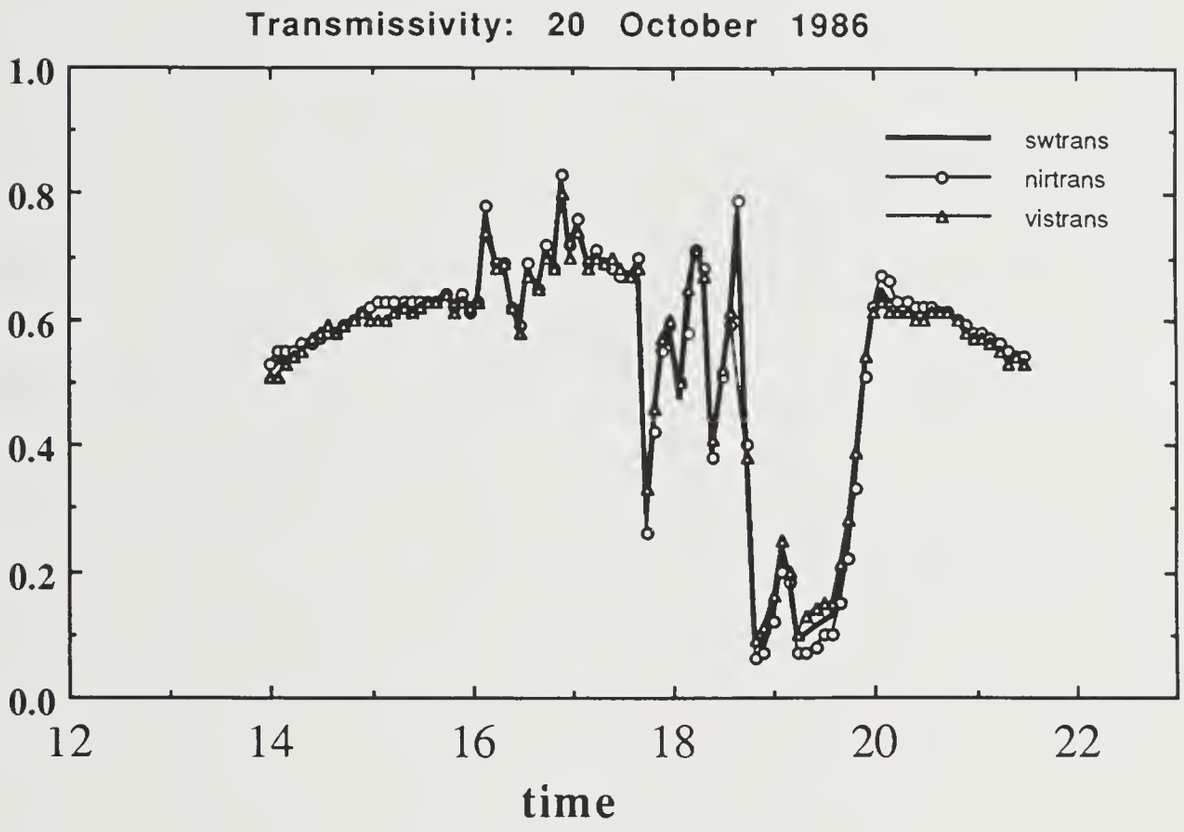

Net Surface Irradiance: 19 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time

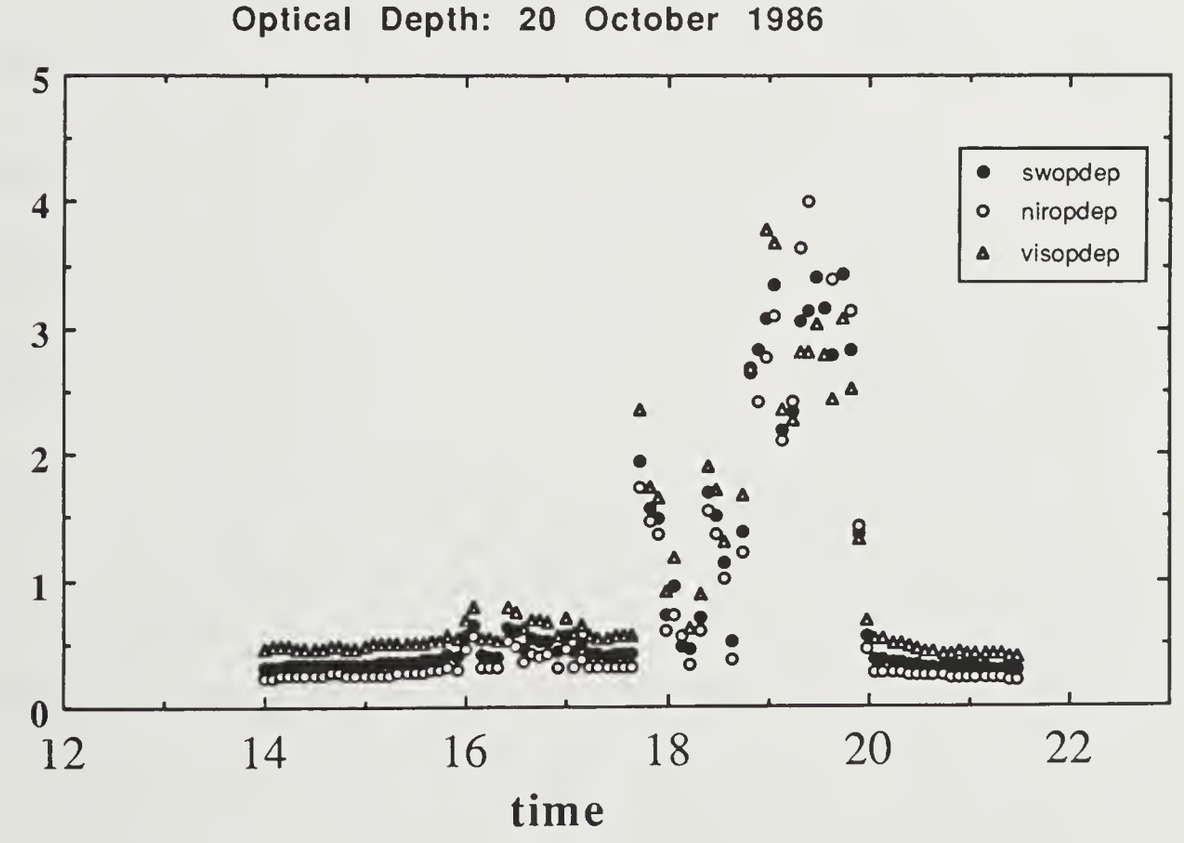

Full Irradiance: 20 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

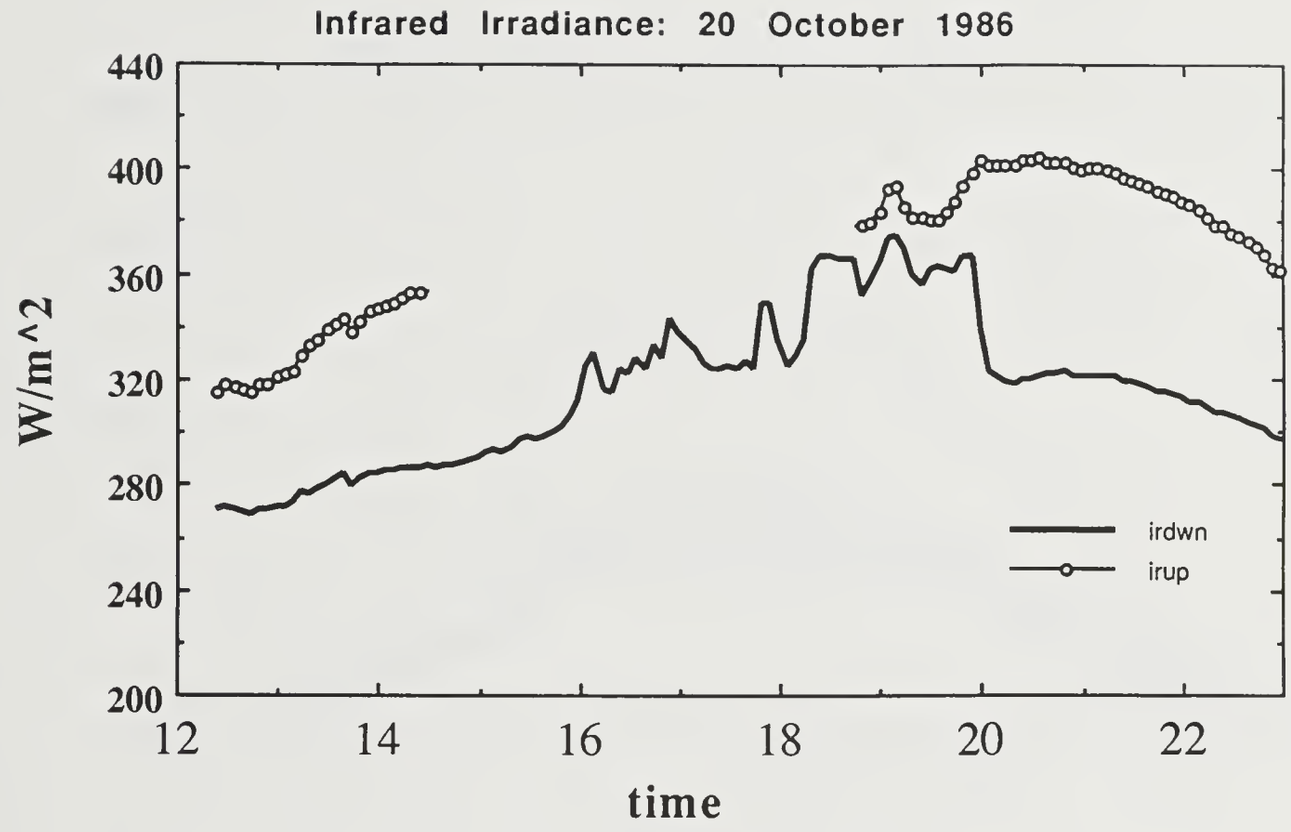

Diffuse Irradiance: 20 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd

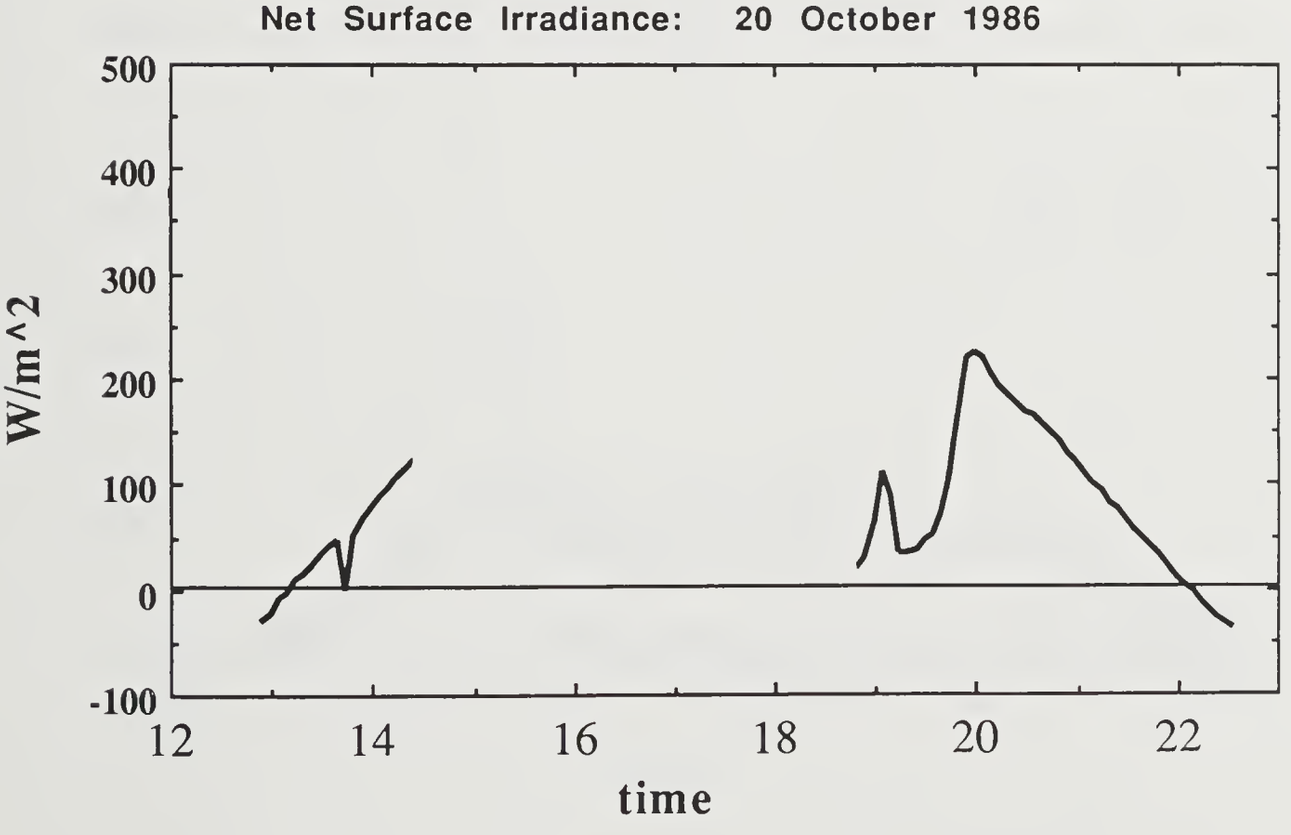

Ratio of NIR to VIS: 20 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time

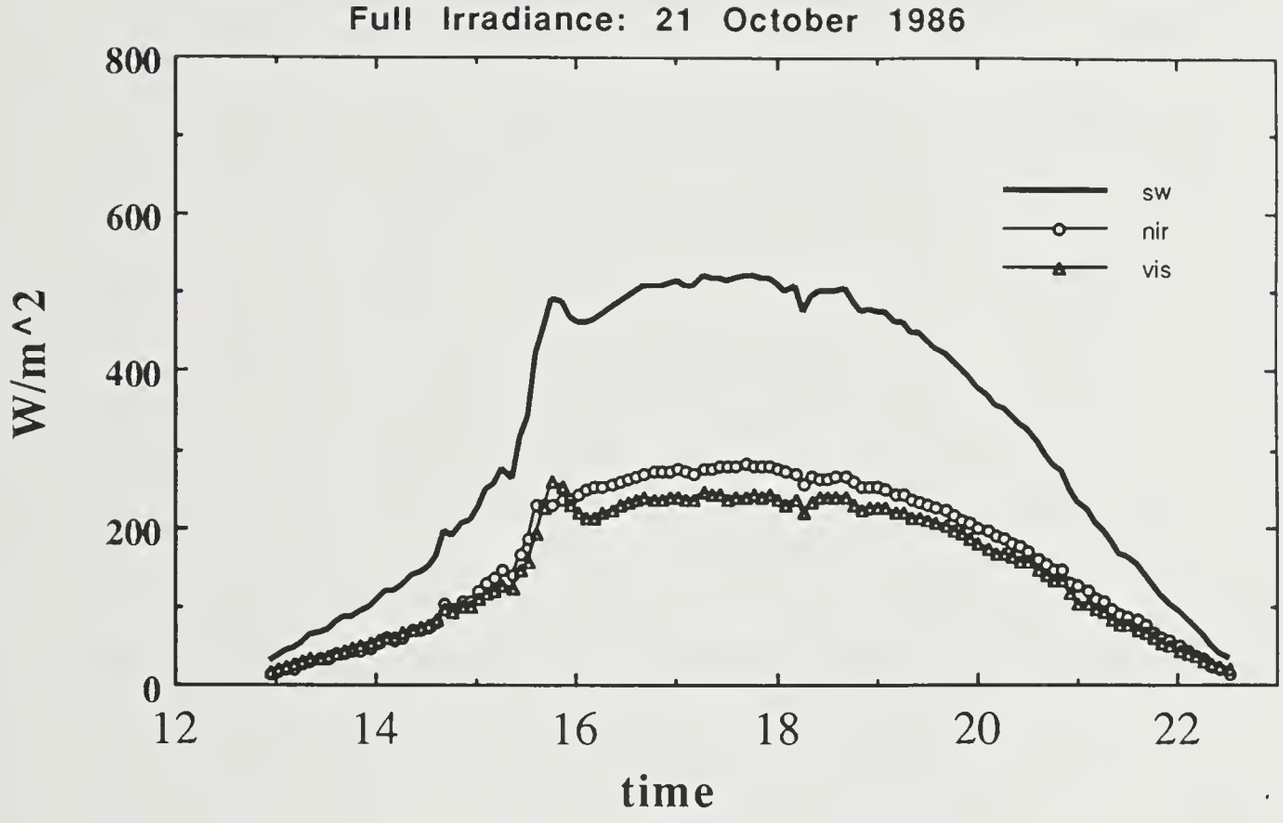

Fraction Diffuse Irradiance: 20 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swdfrac
nirdfrac
visdfrac

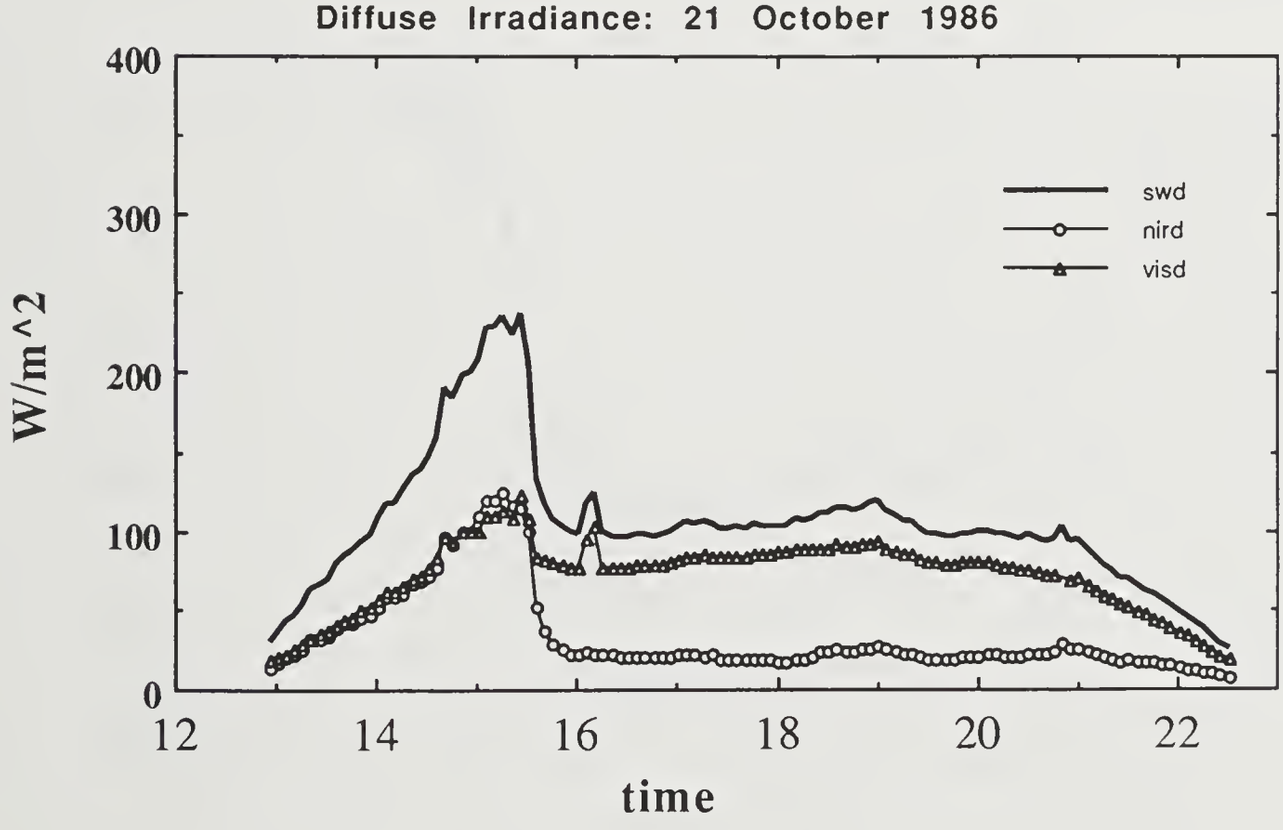

Transmissivity: 20 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

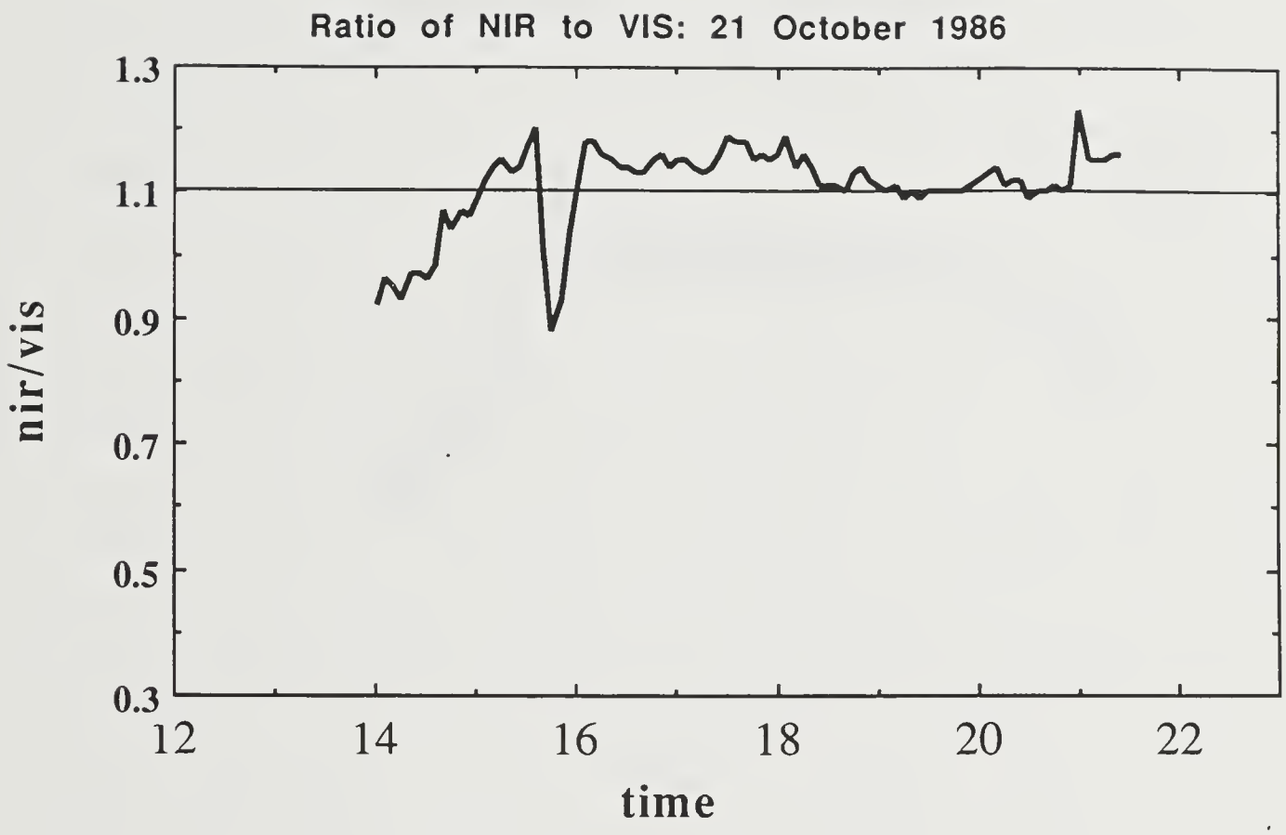

Optical Depth: 20 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep
niropdep
visopdep

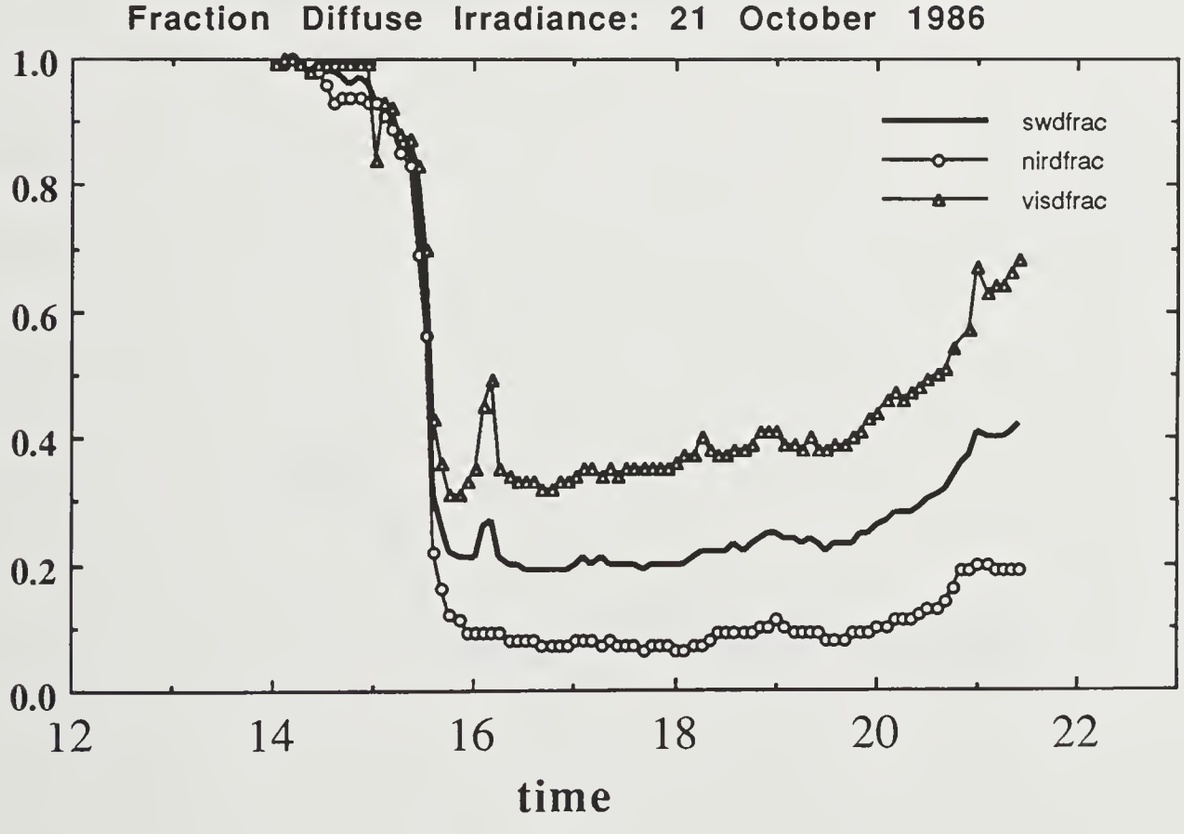

Infrared Irradiance: 20 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn
irup

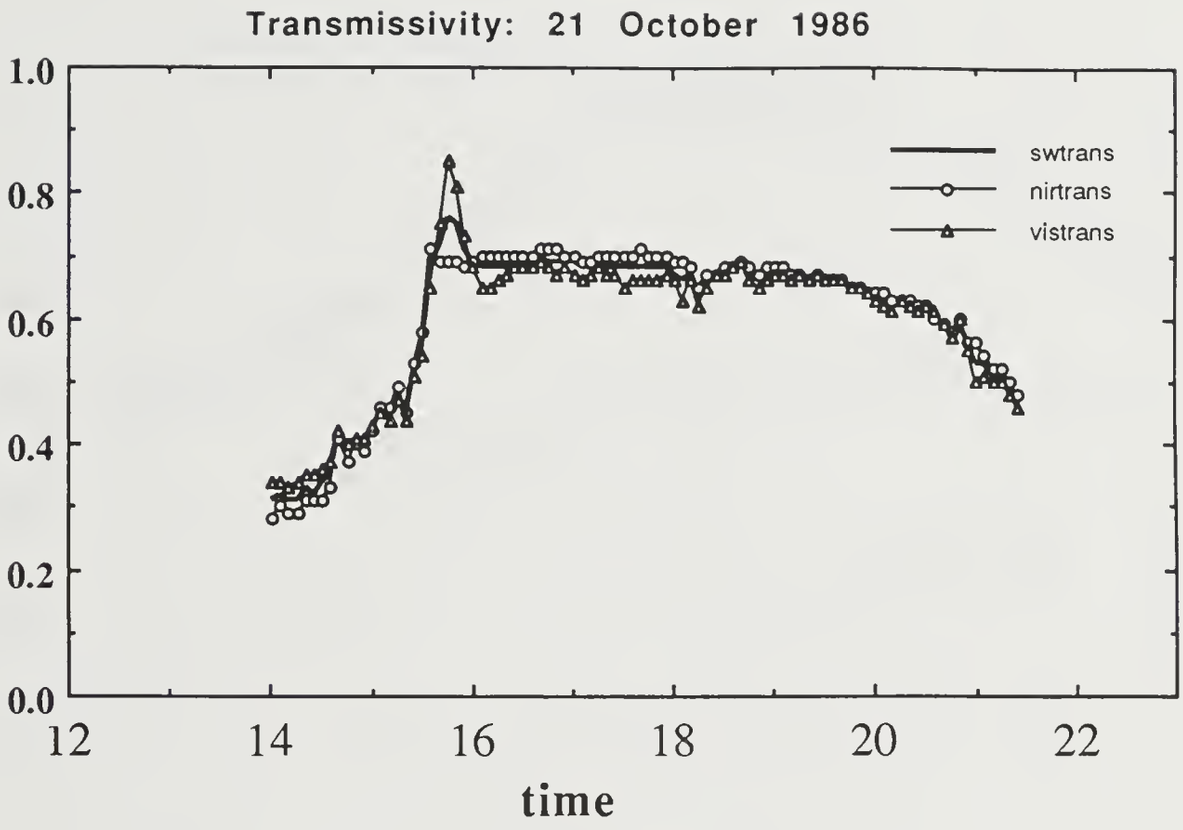

Net Surface Irradiance: 20 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time

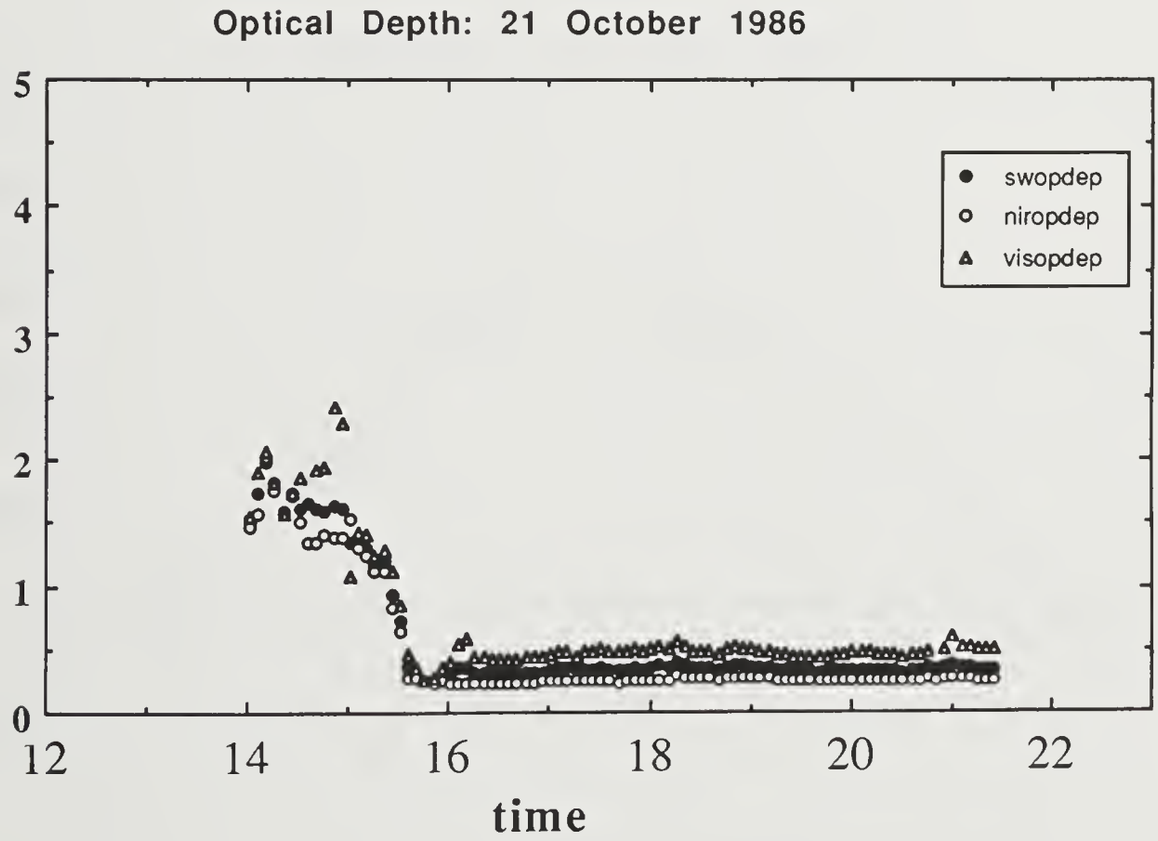

Full Irradiance: 21 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

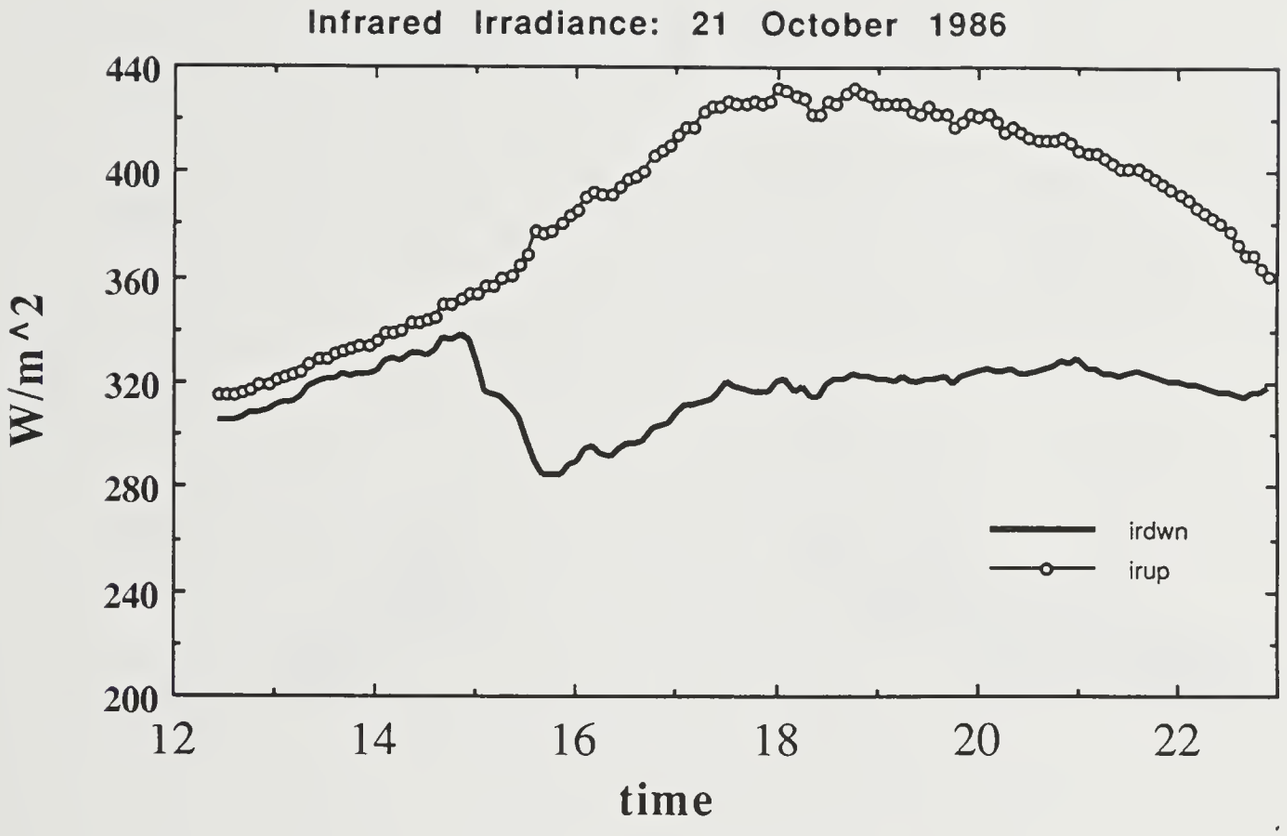

Diffuse Irradiance: 21 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd

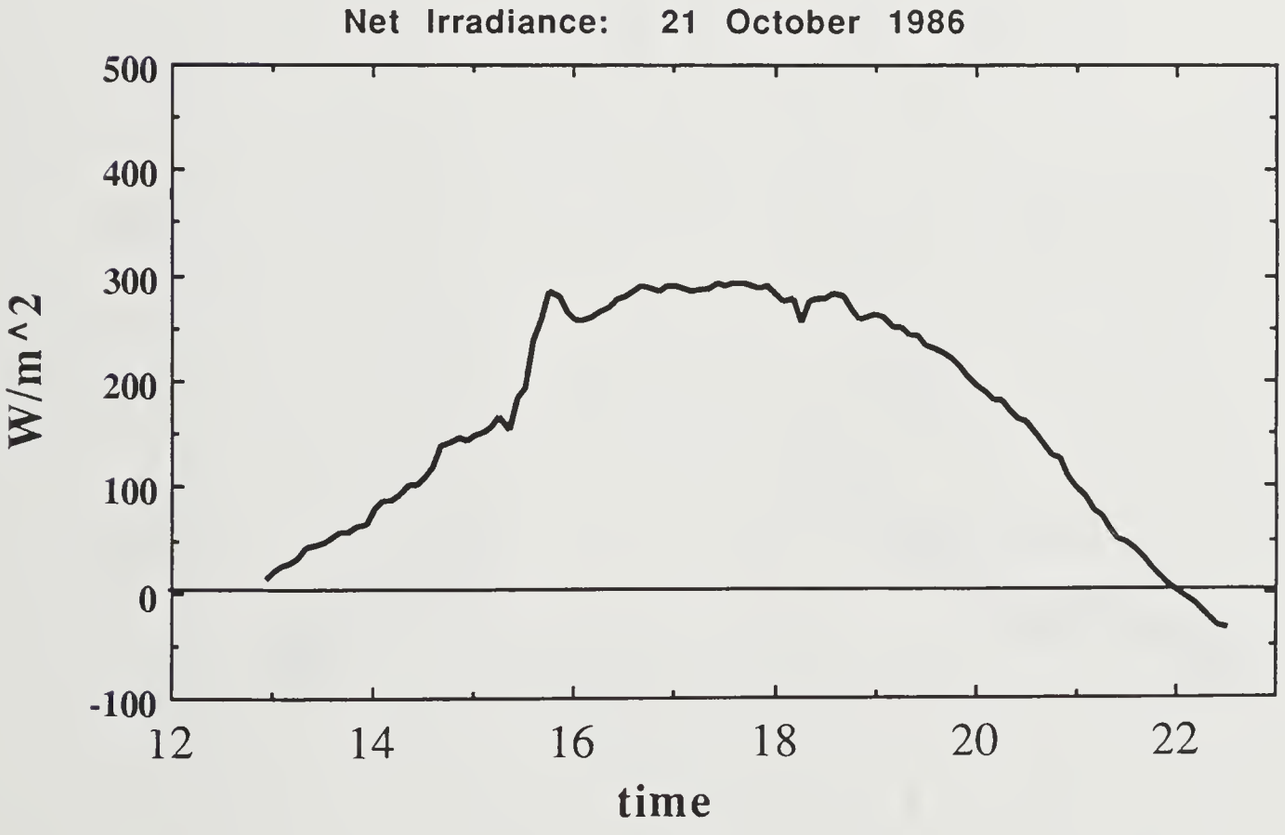

Ratio of NIR to VIS: 21 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time

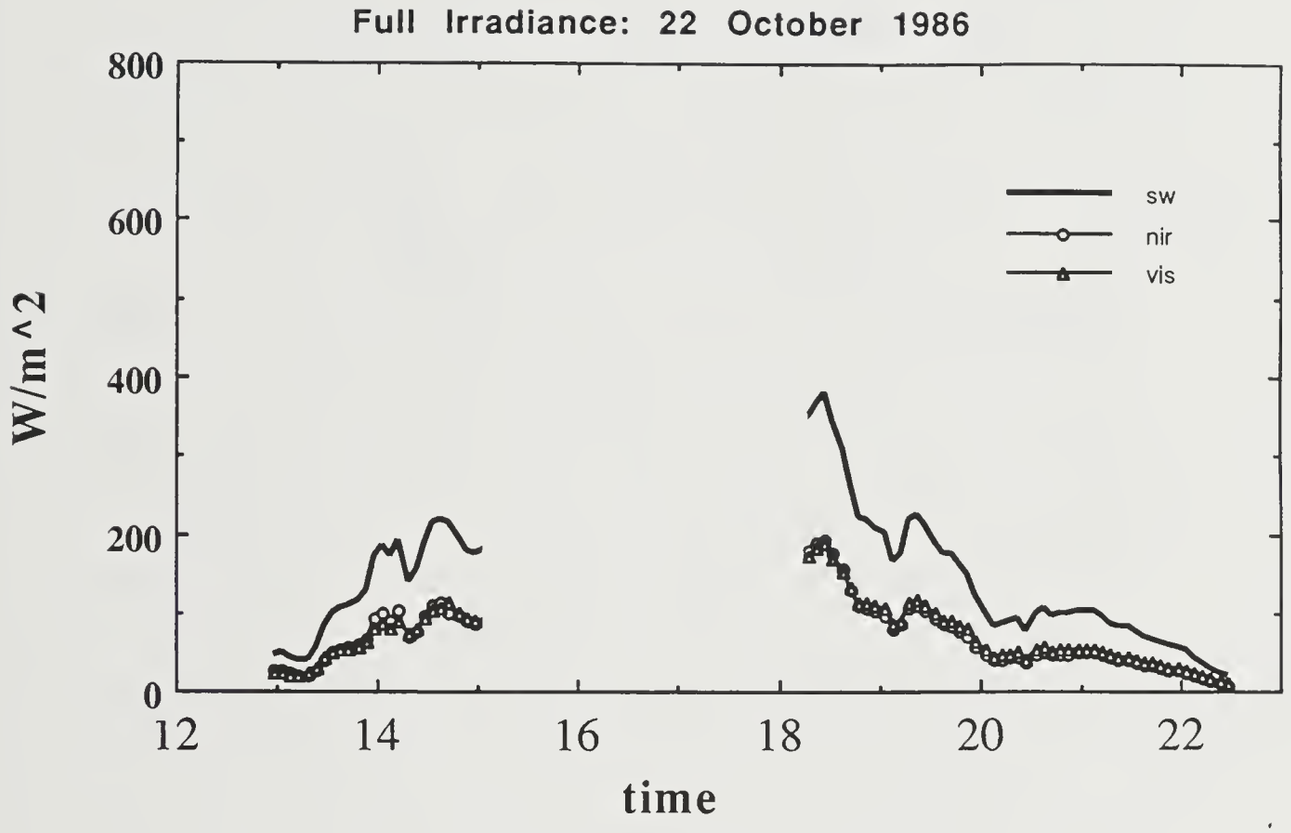

Fraction Diffuse Irradiance: 21 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
swdfrac
nirdfrac
visdfrac
12
14
16
18
20
22
time

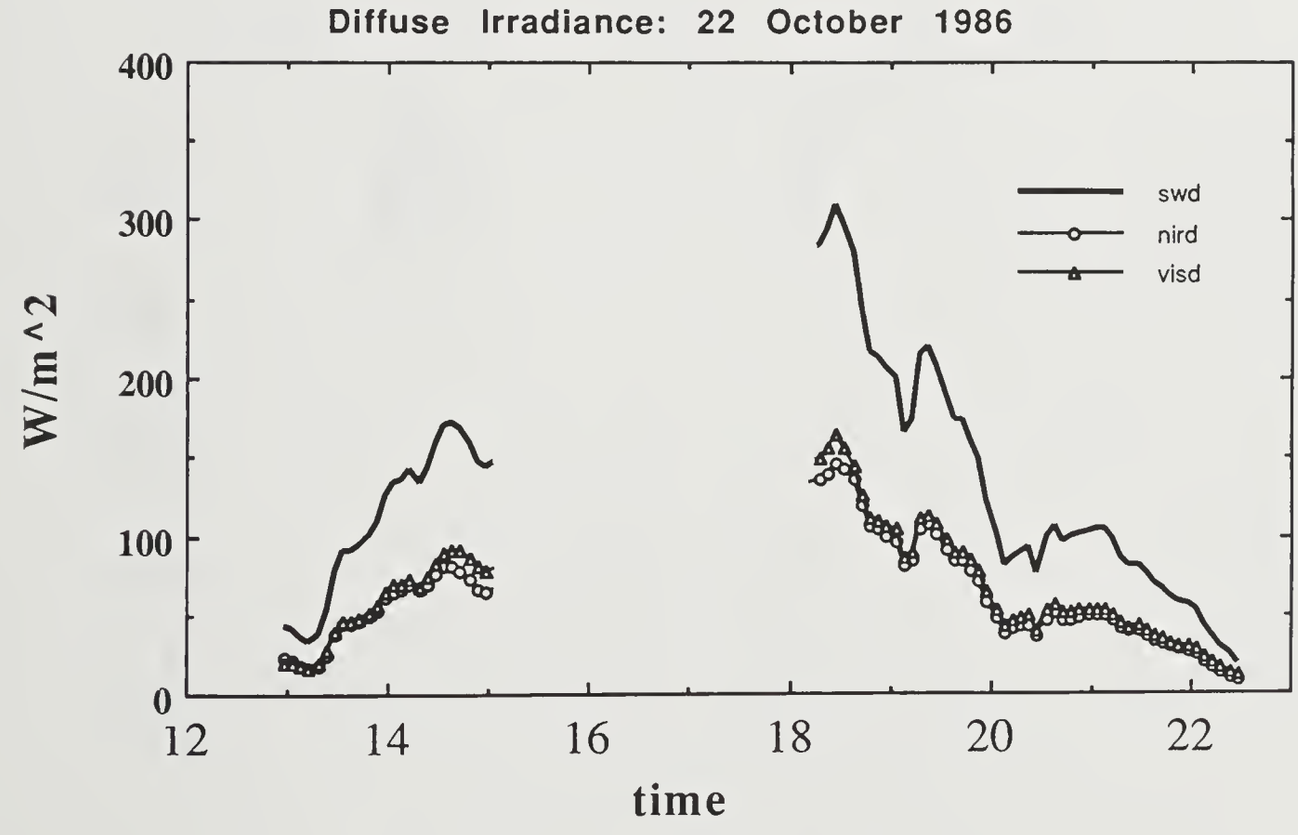

Transmissivity: 21 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

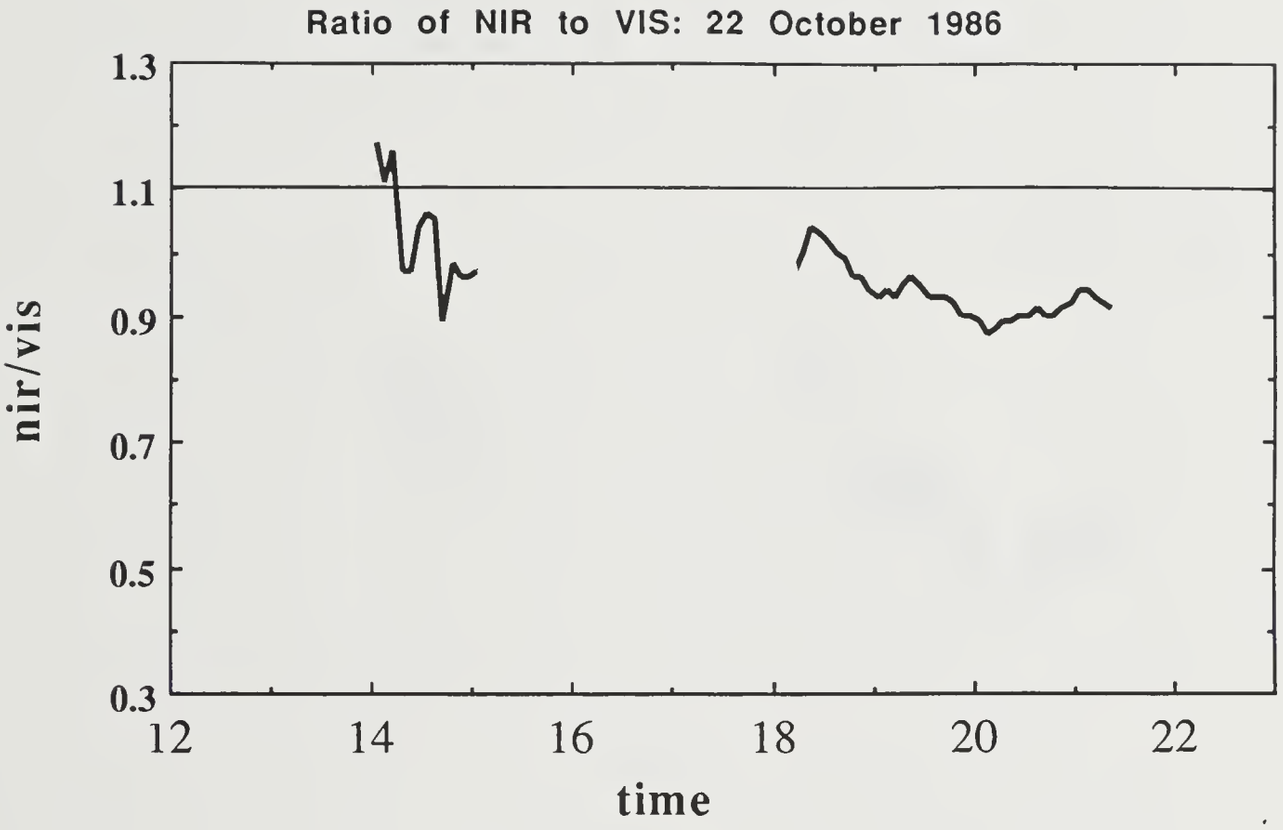

Optical Depth: 21 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep
niropdep
visopdep

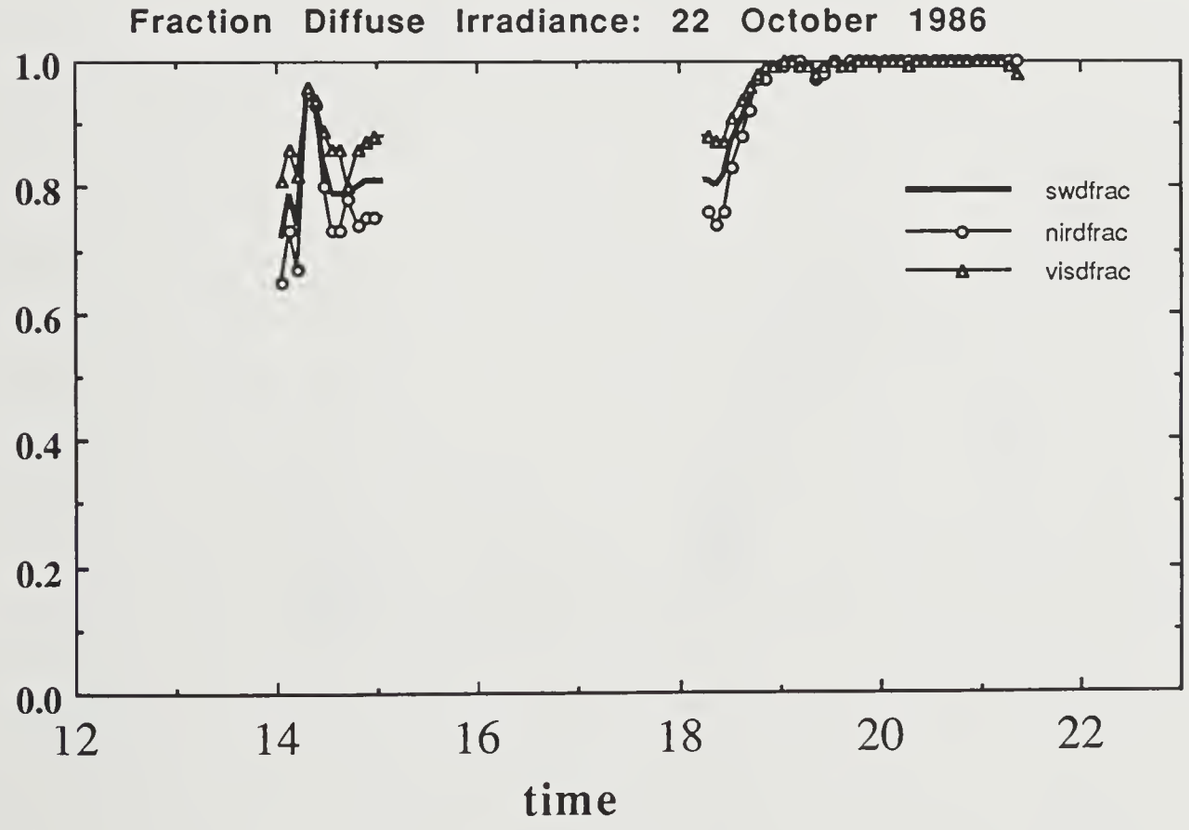

Infrared Irradiance: 21 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn
irup

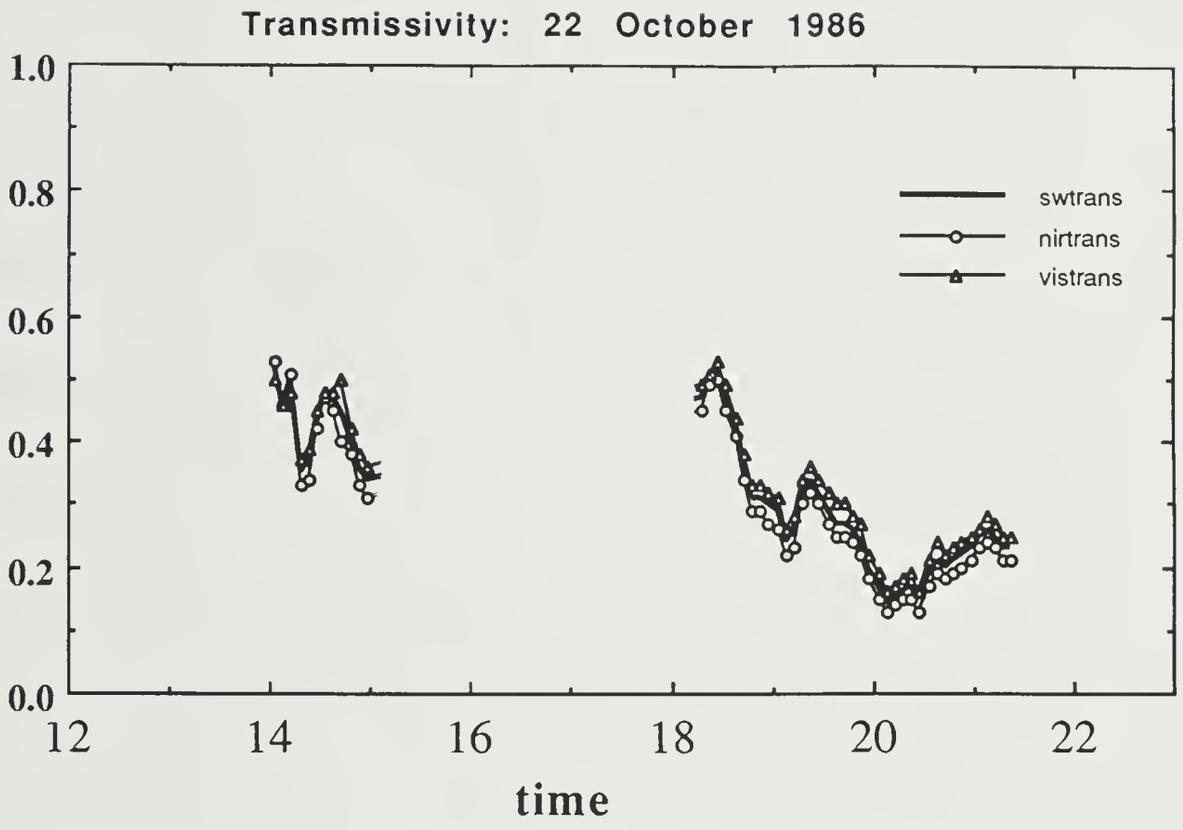

Net Irradiance: 21 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time

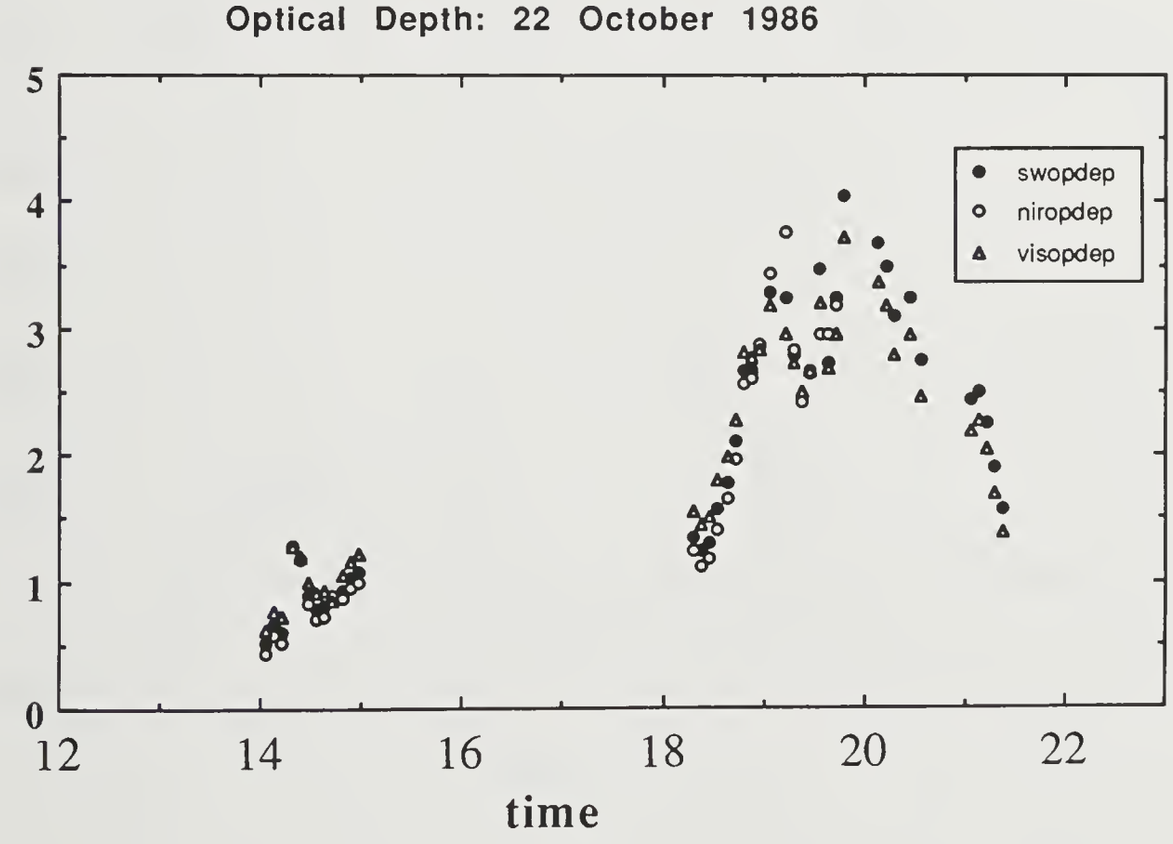

Full Irradiance: 22 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

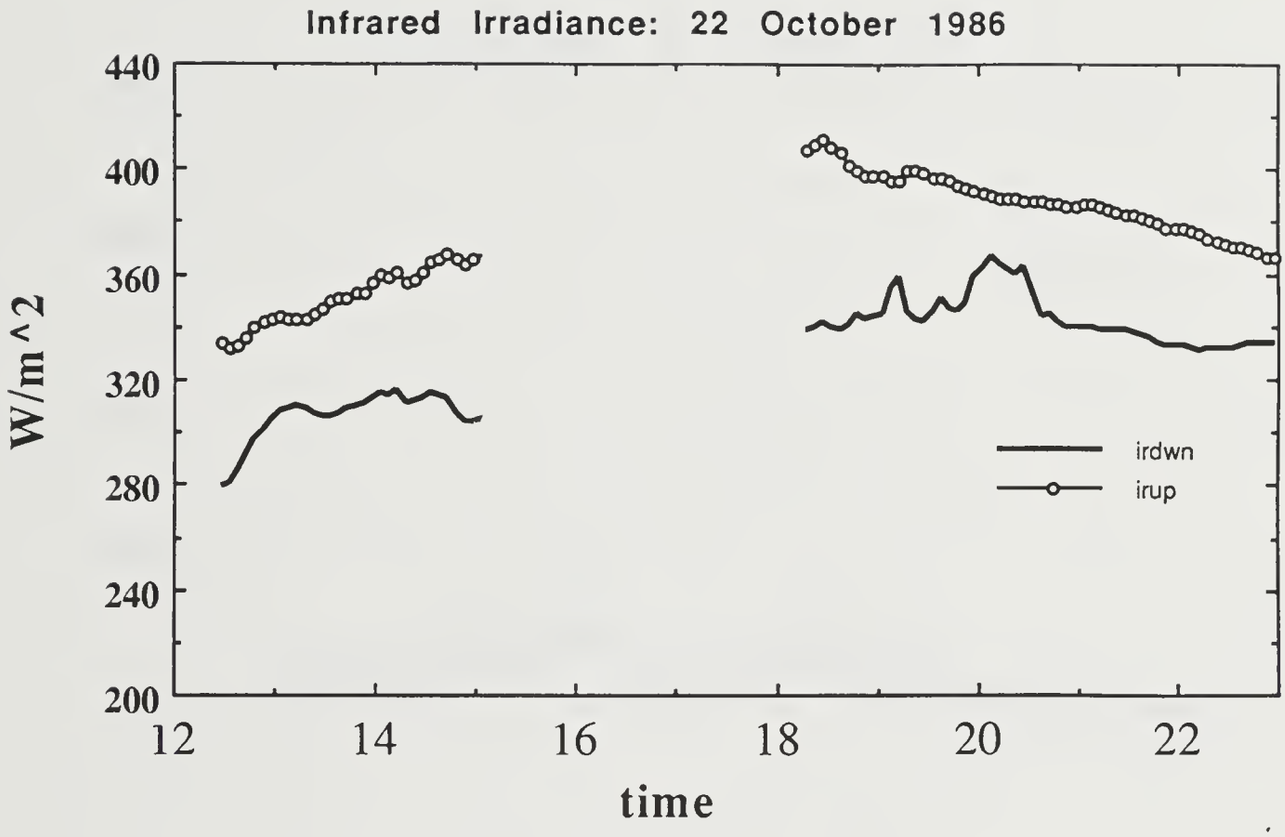

Diffuse Irradiance: 22 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd

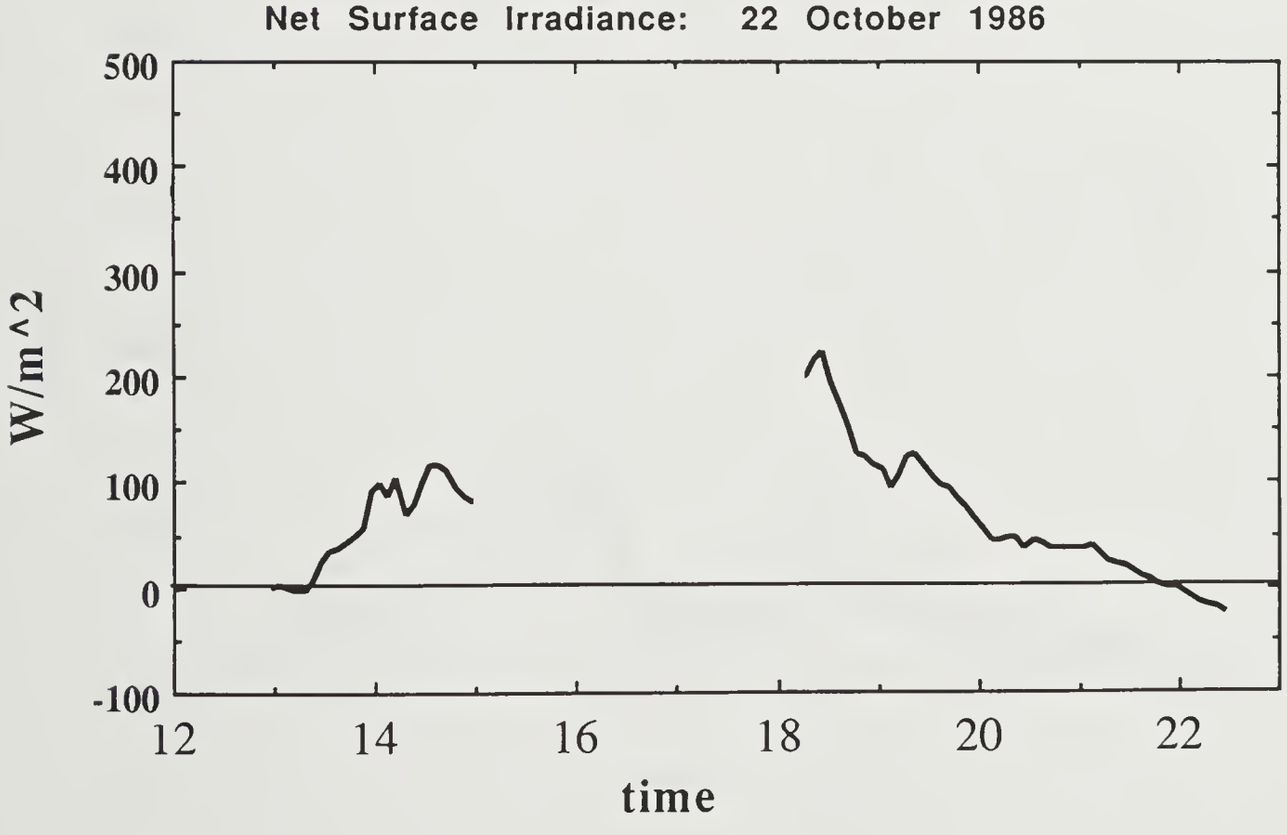

Ratio of NIR to VIS: 22 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time

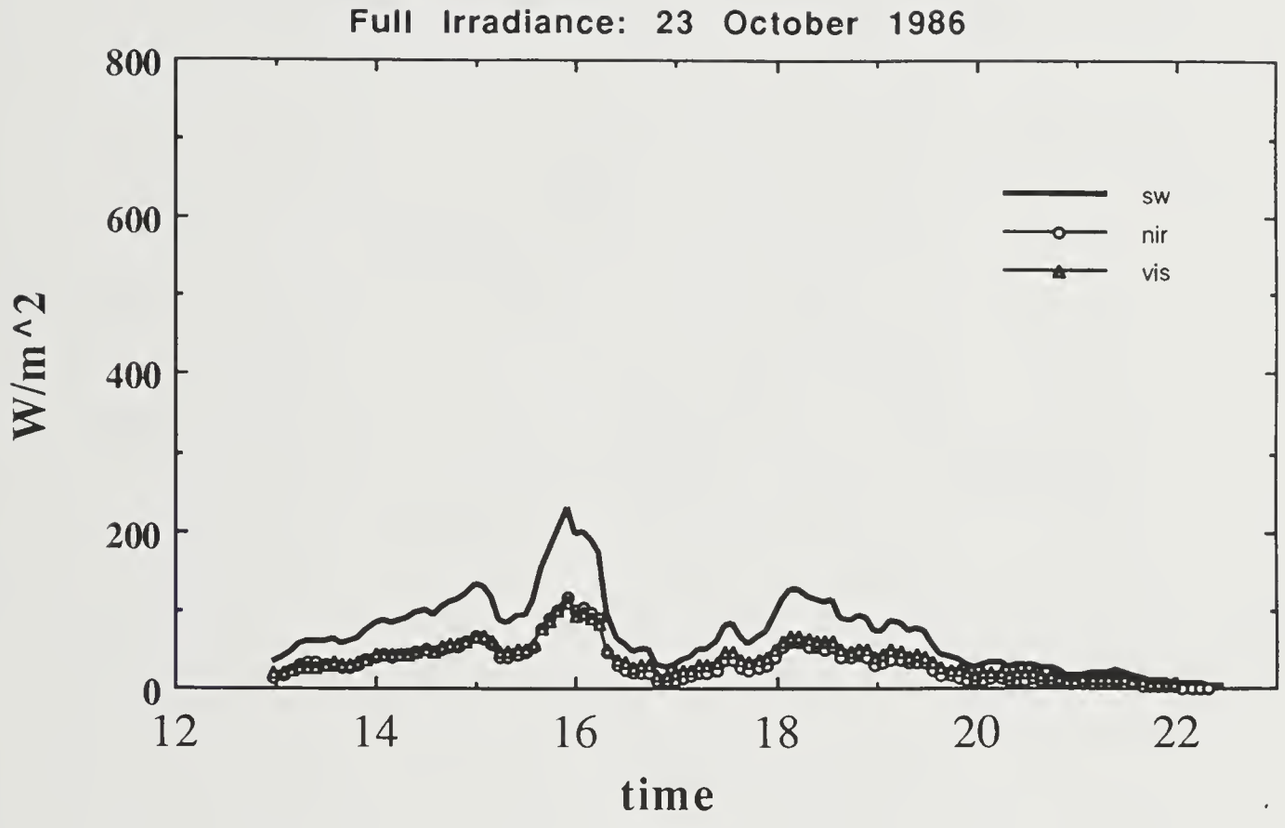

Fraction Diffuse Irradiance: 22 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swdfrac
nirdfrac
visdfrac

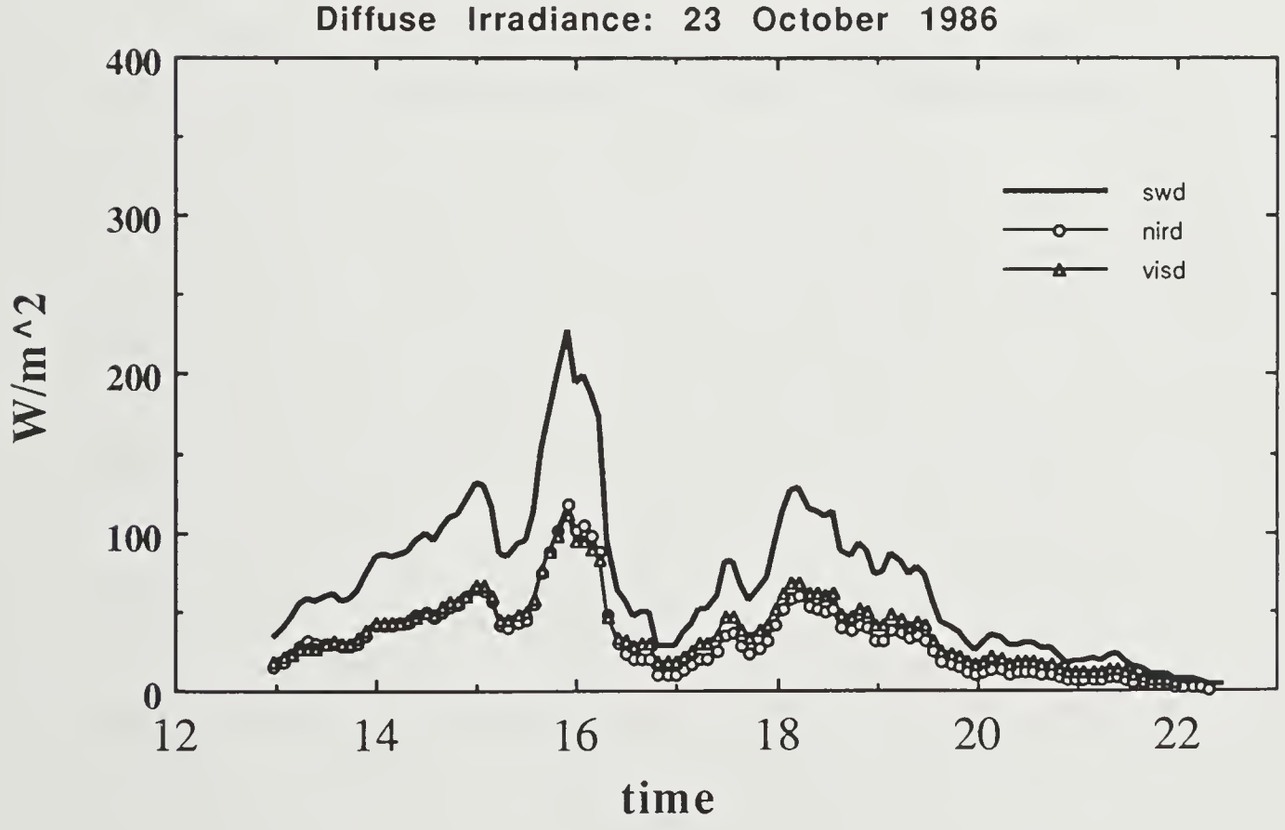

Transmissivity: 22 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

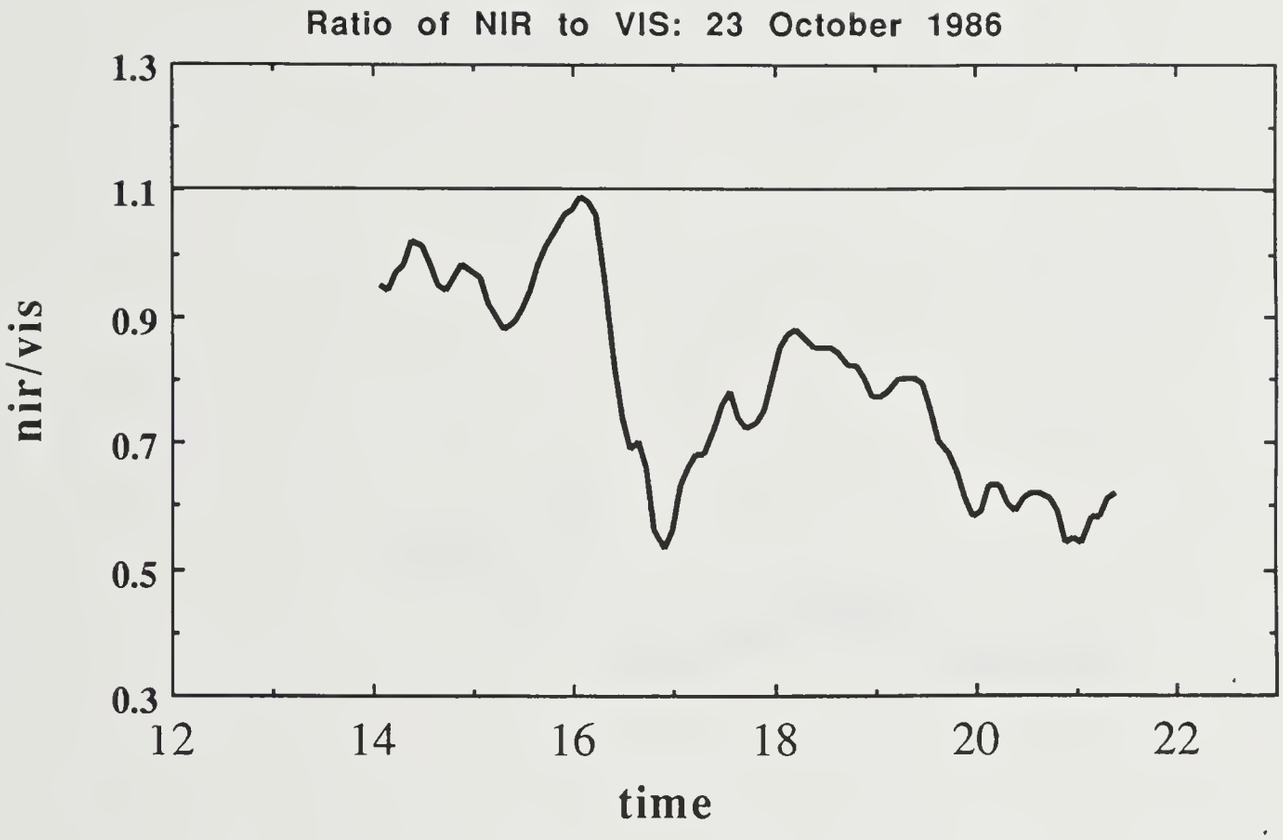

Optical Depth: 22 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep
niropdep
visopdep

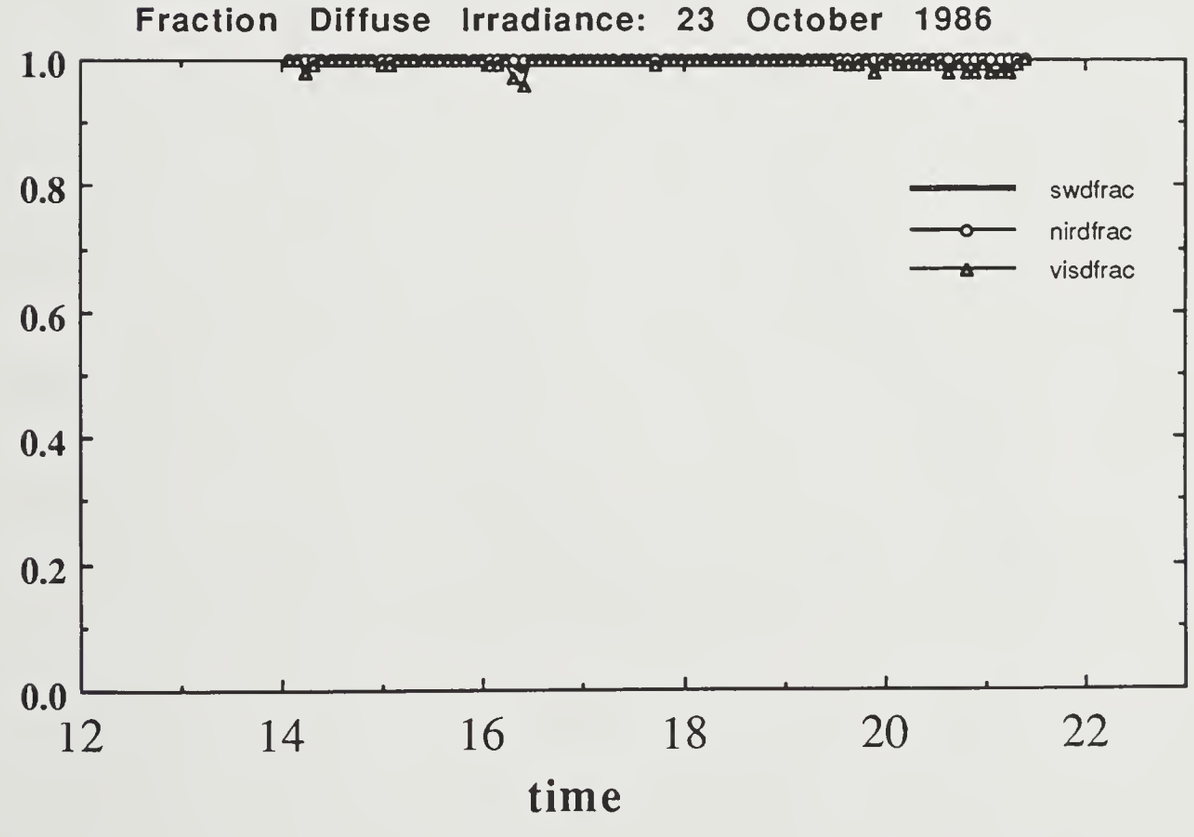

Infrared Irradiance: 22 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn
irup

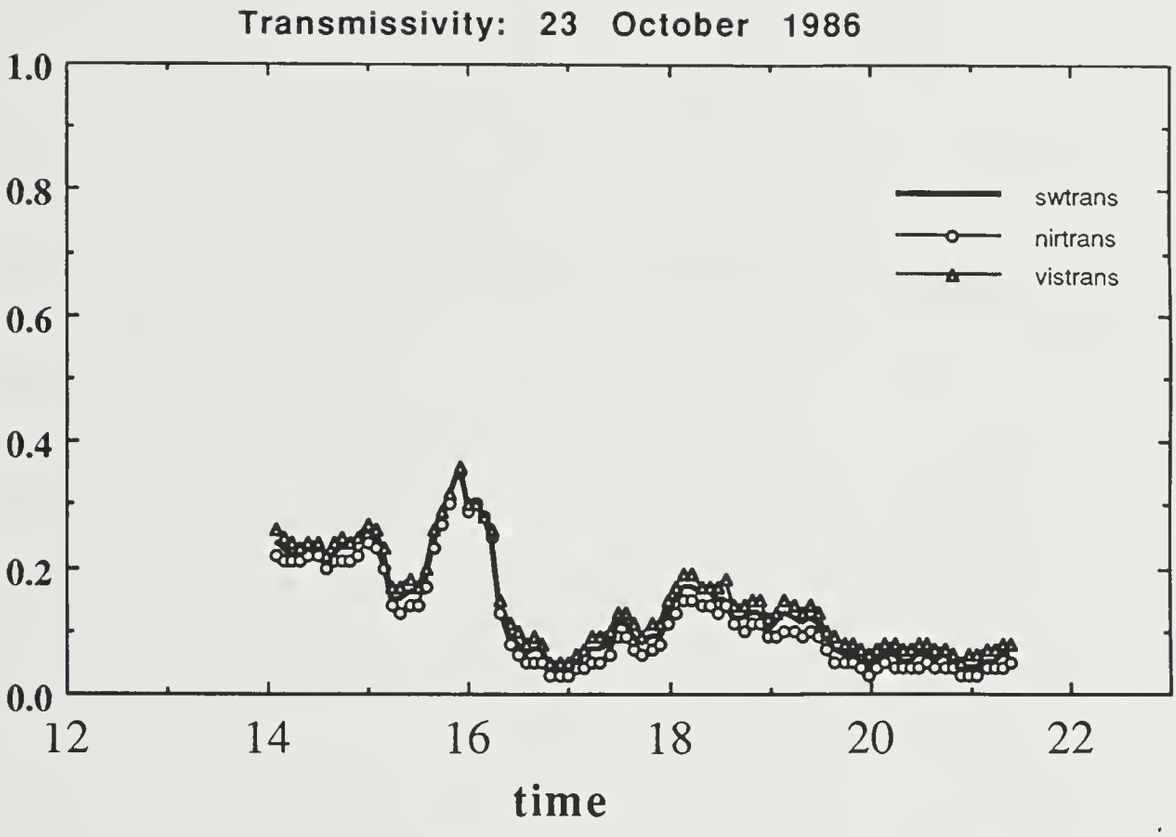

Net Surface Irradiance: 22 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time

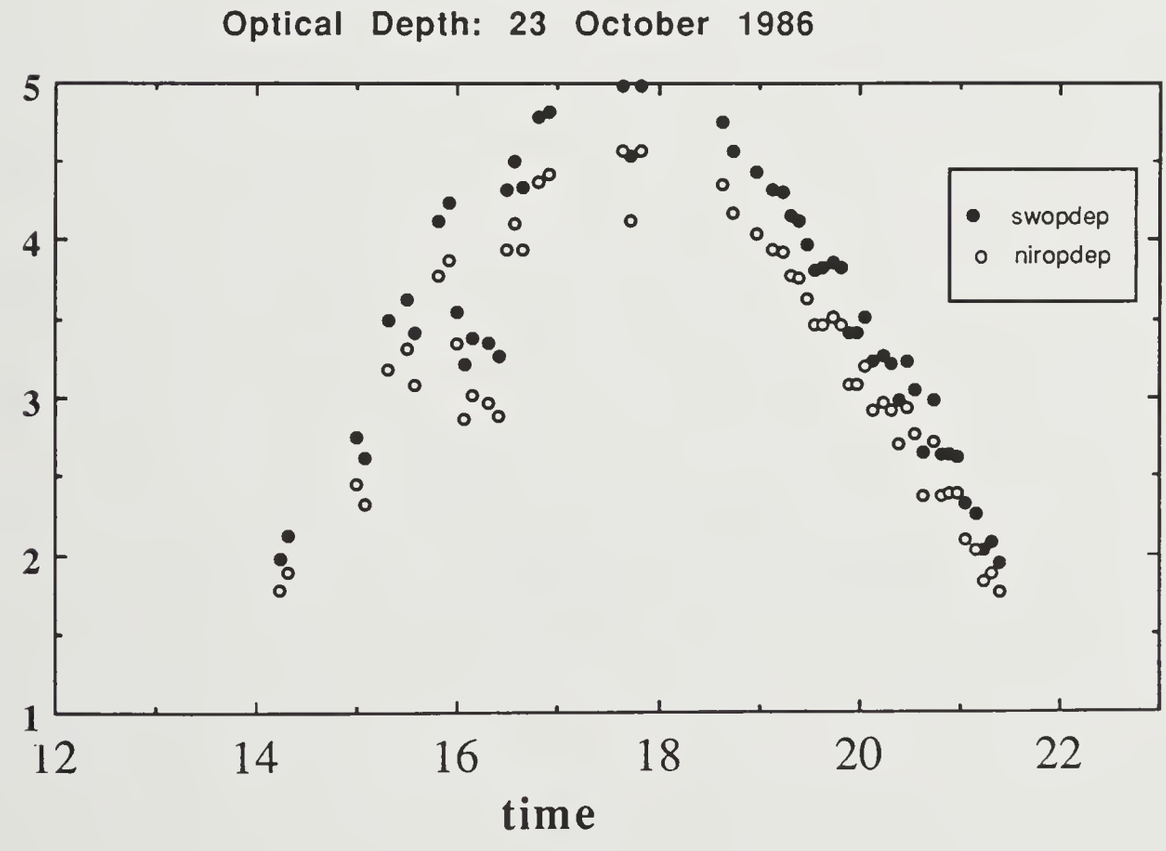

Full Irradiance: 23 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis


Diffuse Irradiance: 23 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd


Ratio of NIR to VIS: 23 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time


Fraction Diffuse Irradiance: 23 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
swdfrac
nirdfrac
visdfrac
12
14
16
18
20
22
time


Transmissivity: 23 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans


Optical Depth: 23 October 1986
5
4
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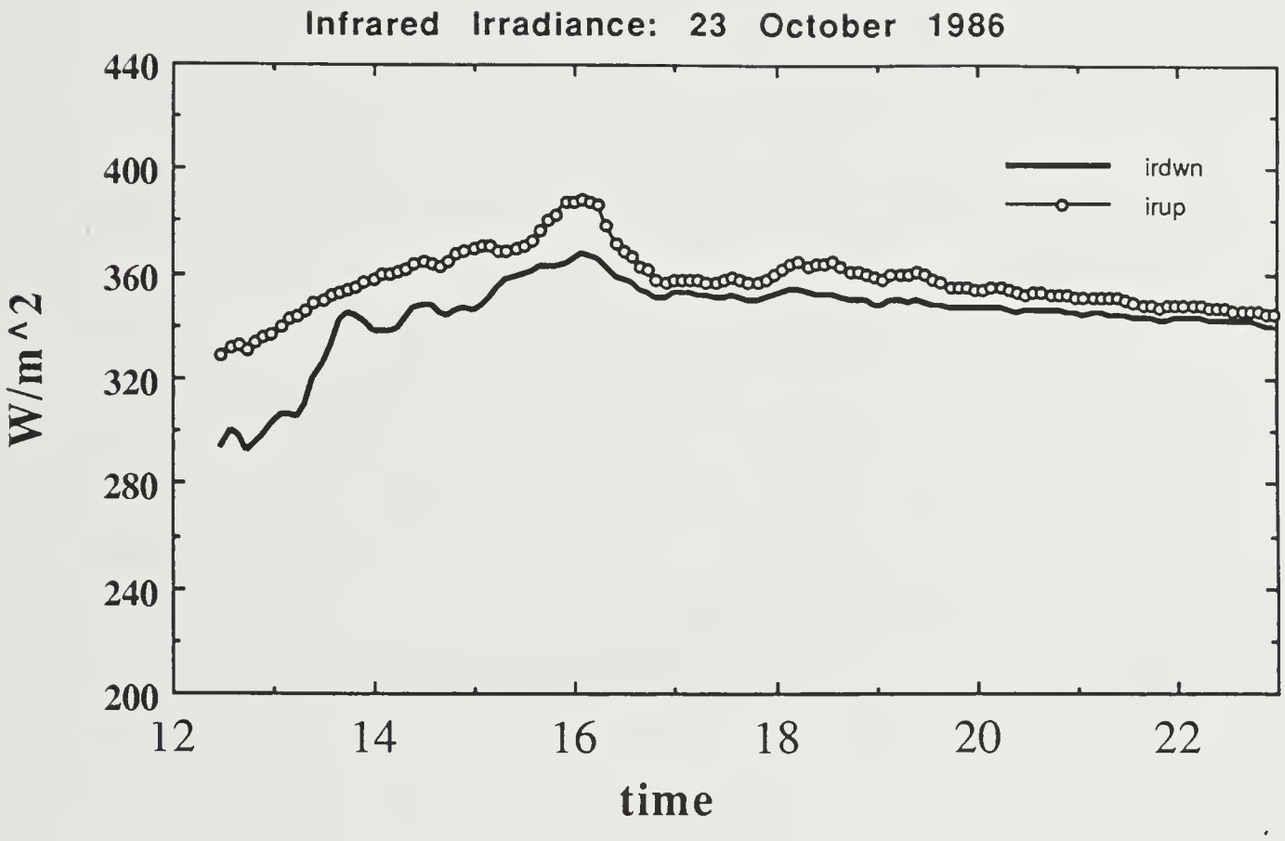
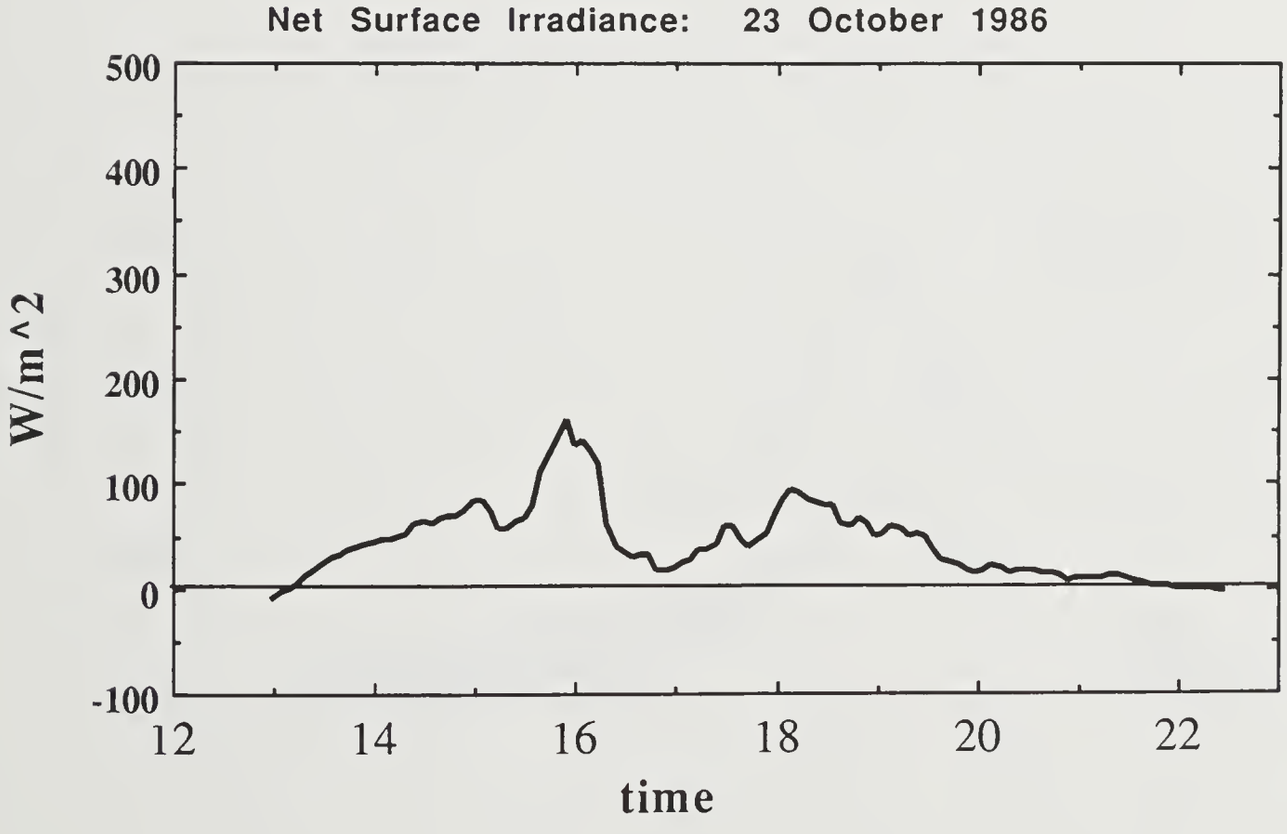
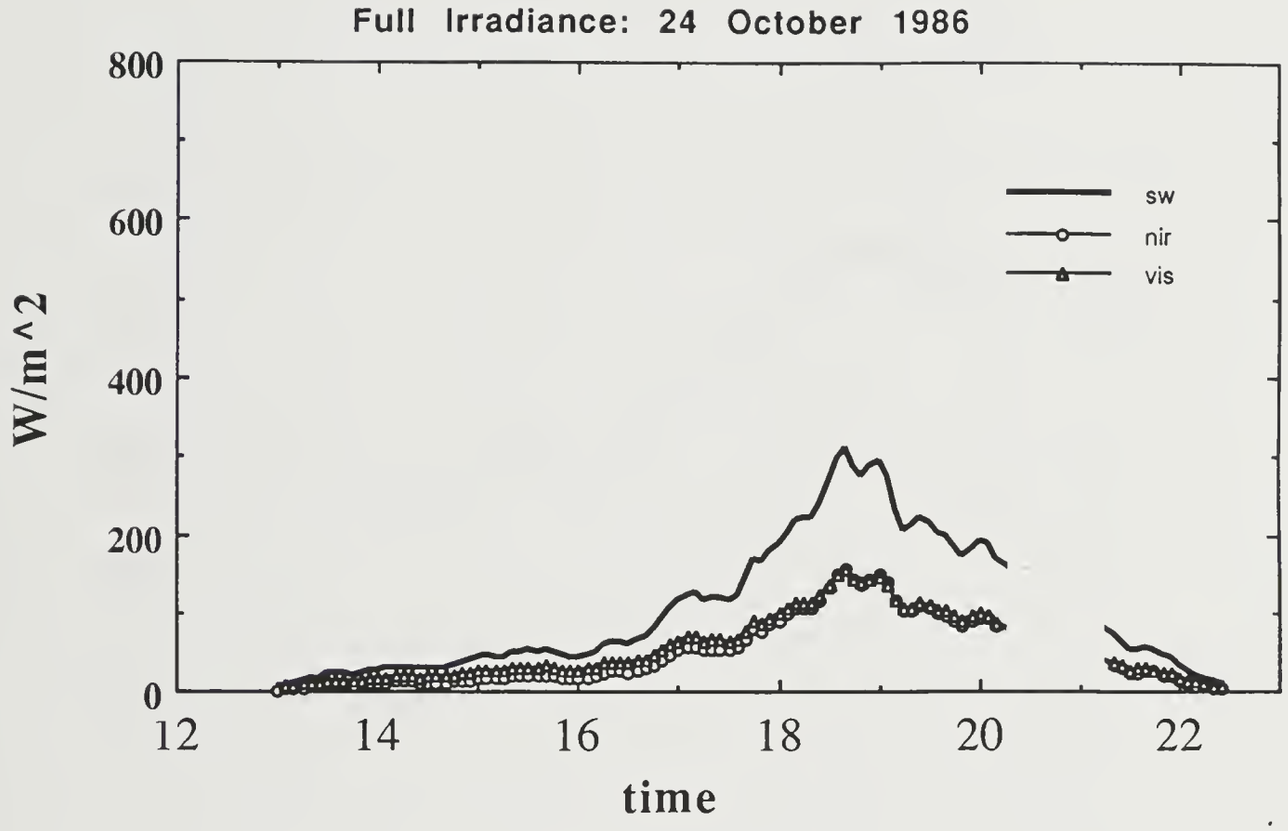
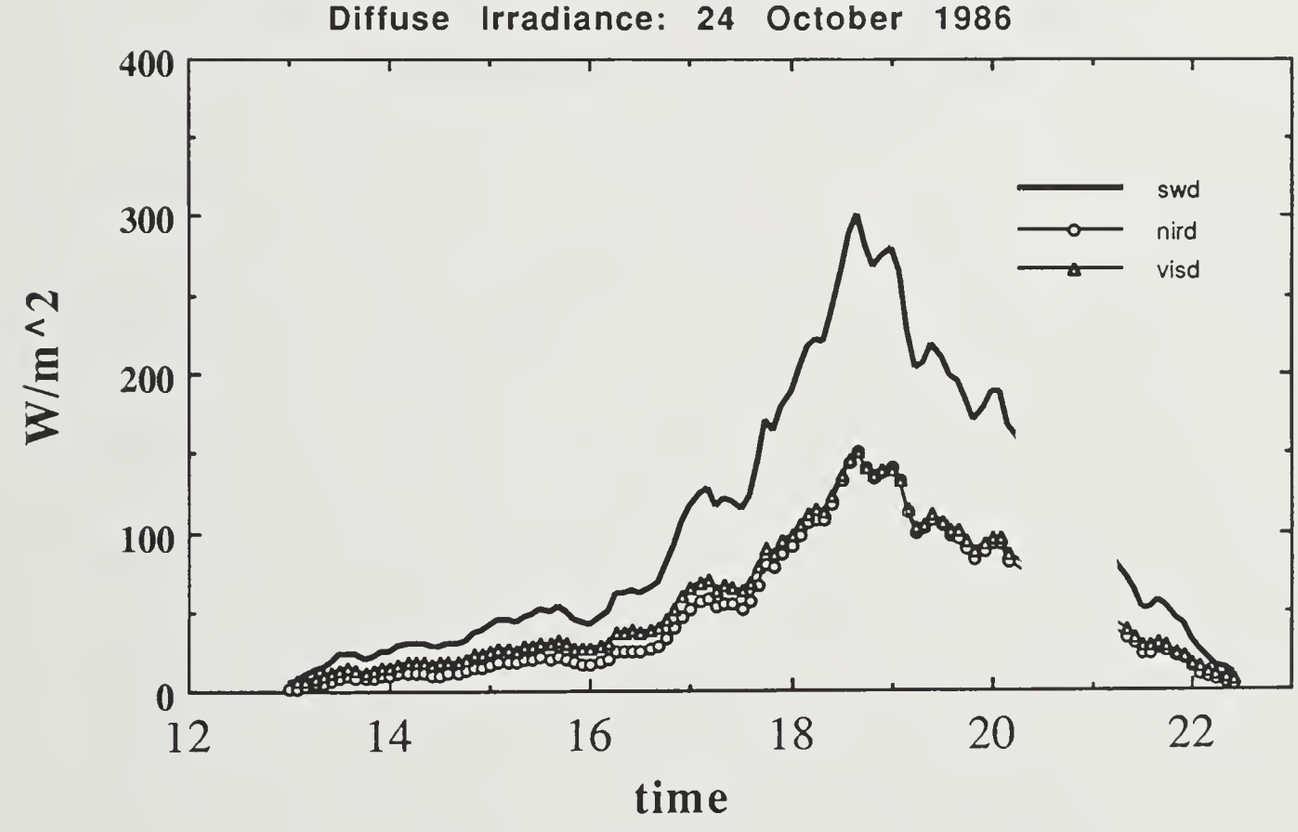
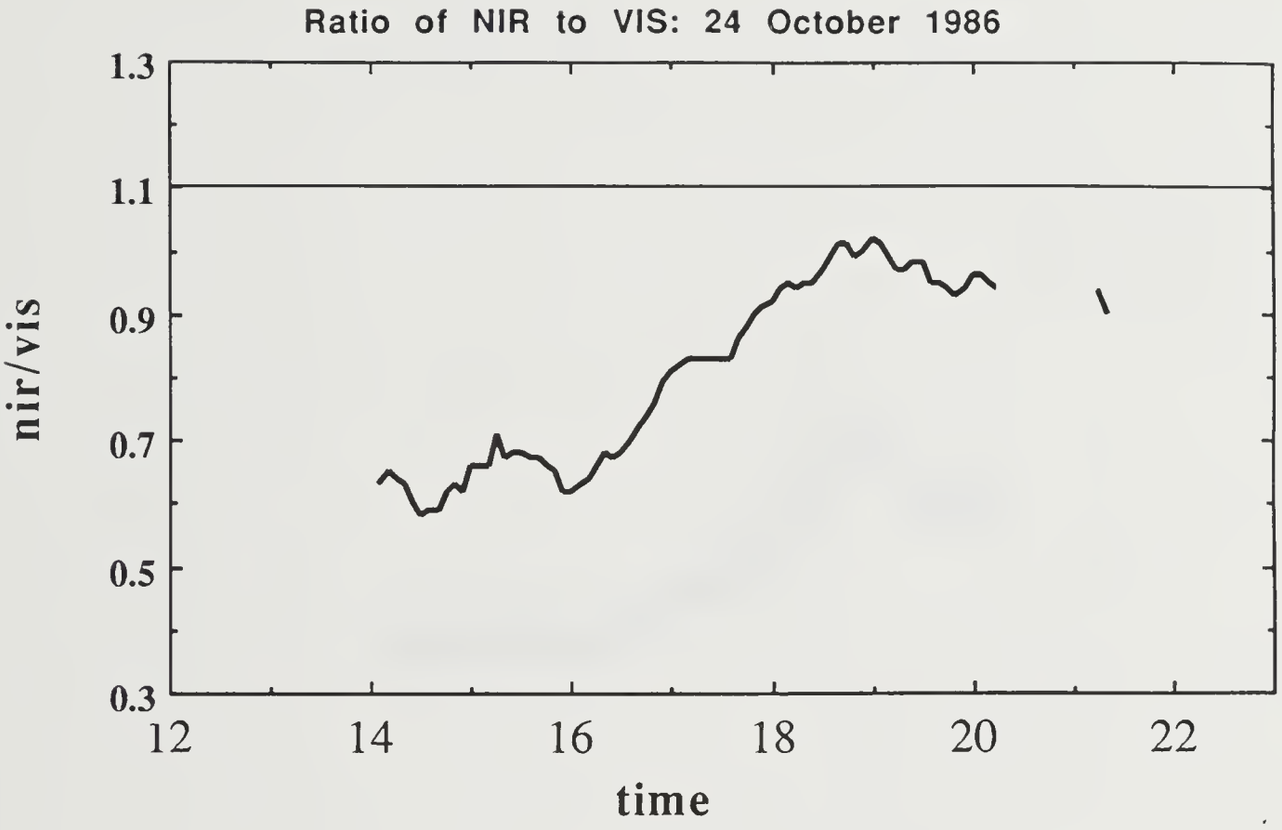
2
1
12
14
16
18
20
22
time
swopdep
niropdep

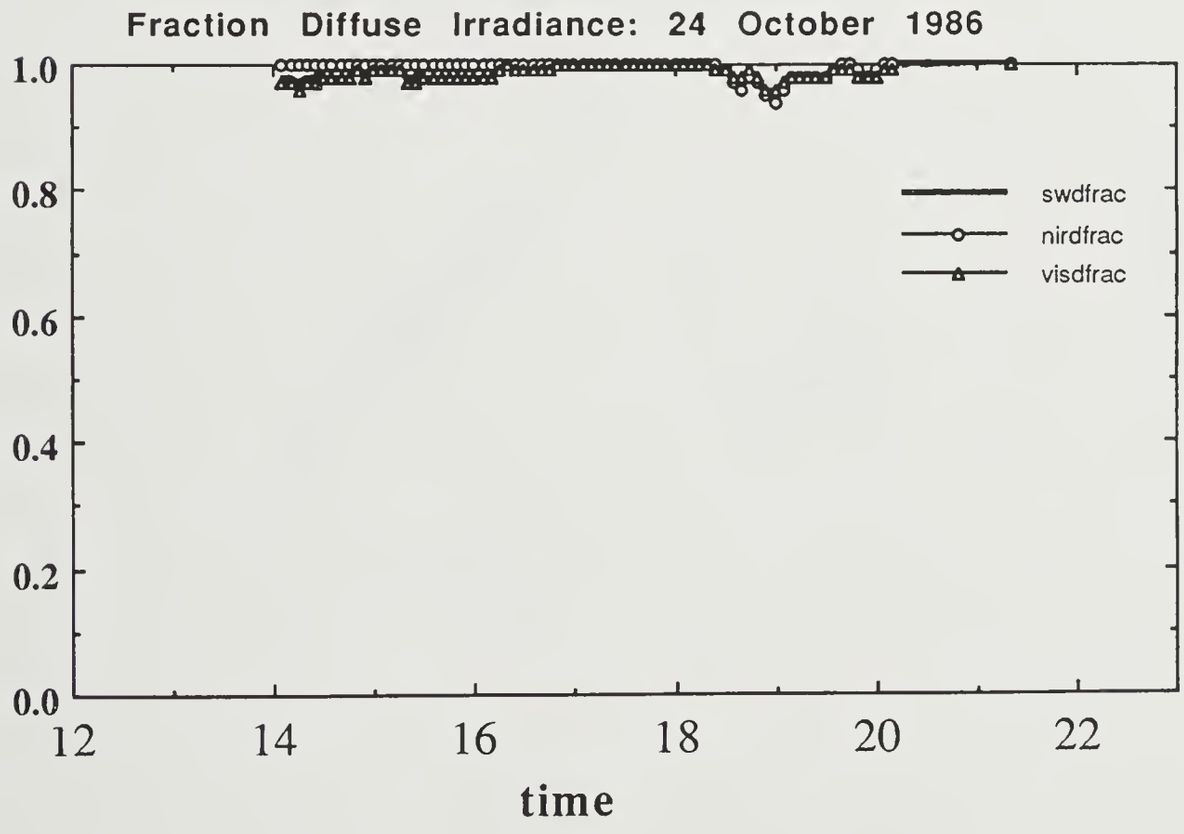

Infrared Irradiance: 23 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn
irup

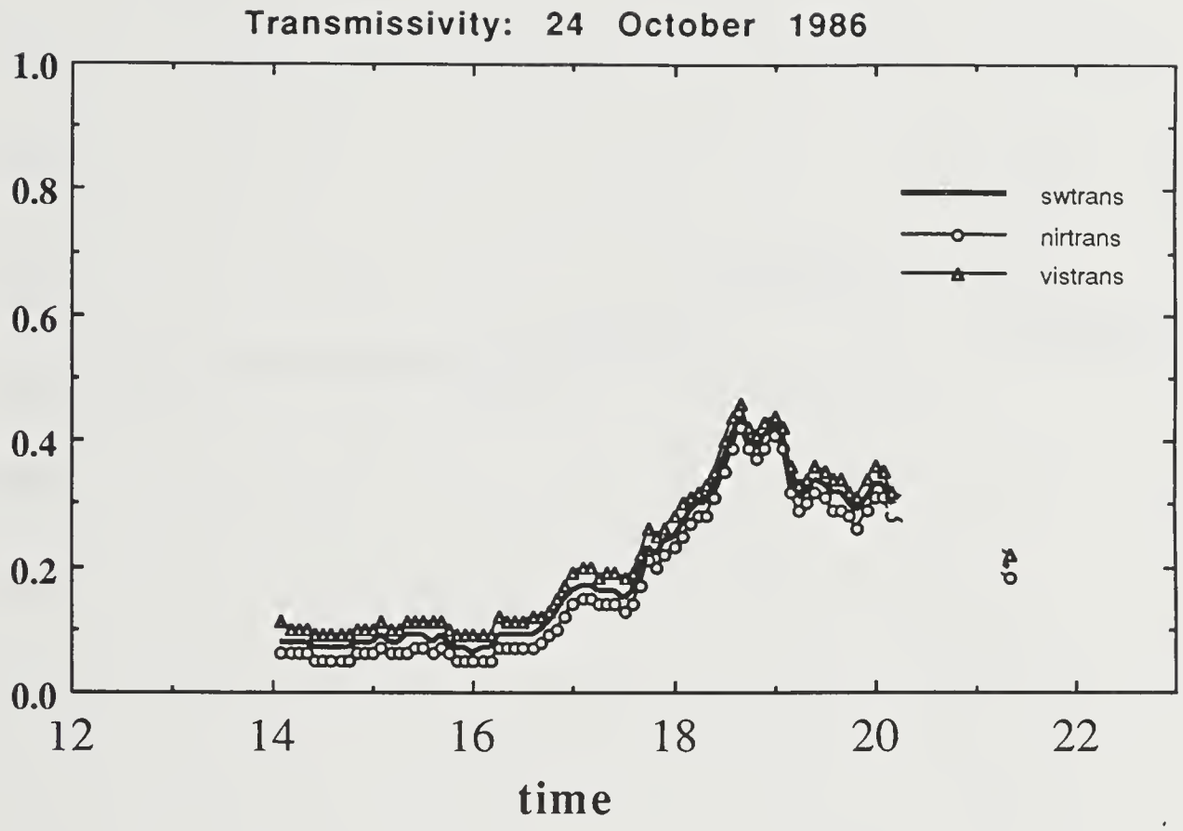

Net Surface Irradiance: 23 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time


Full Irradiance: 24 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis


Diffuse Irradiance: 24 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd


Ratio of NIR to VIS: 24 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time


Fraction Diffuse Irradiance: 24 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
swdfrac
nirdfrac
visdfrac
12
14
16
18
20
22
time


Transmissivity: 24 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
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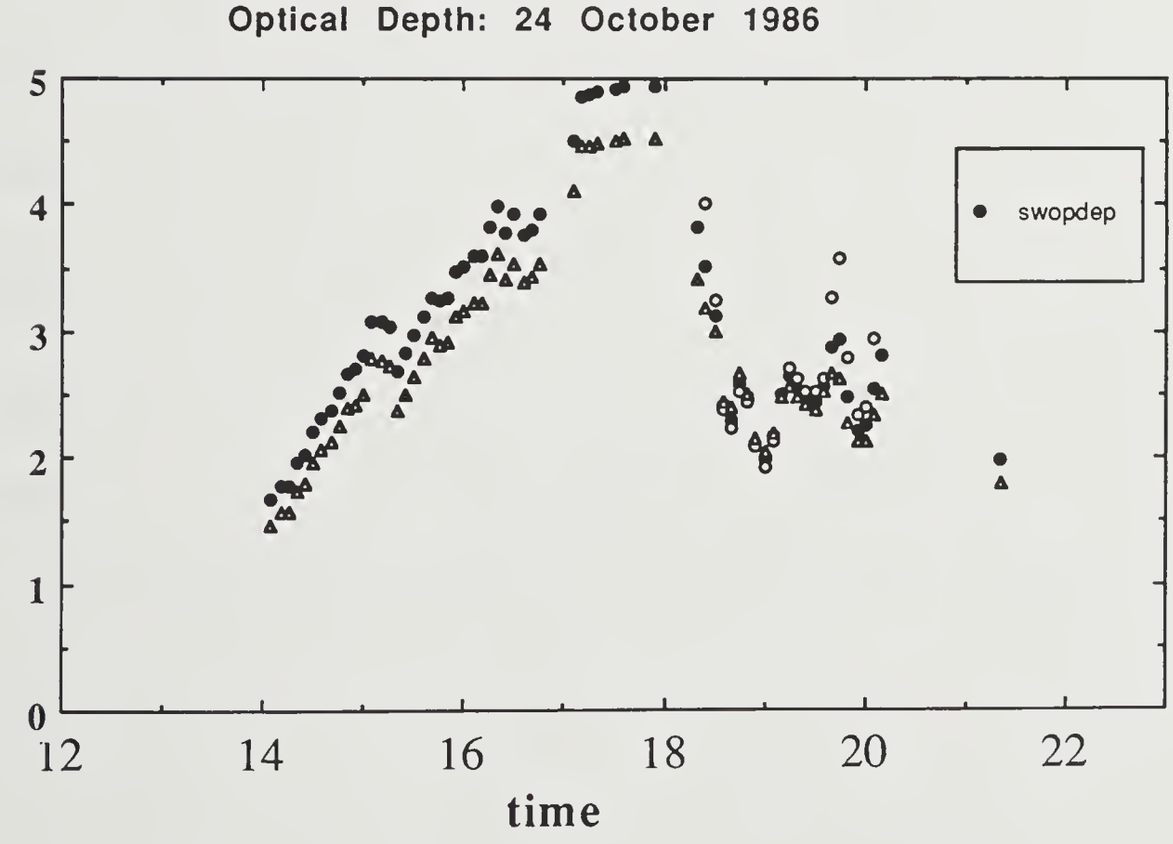
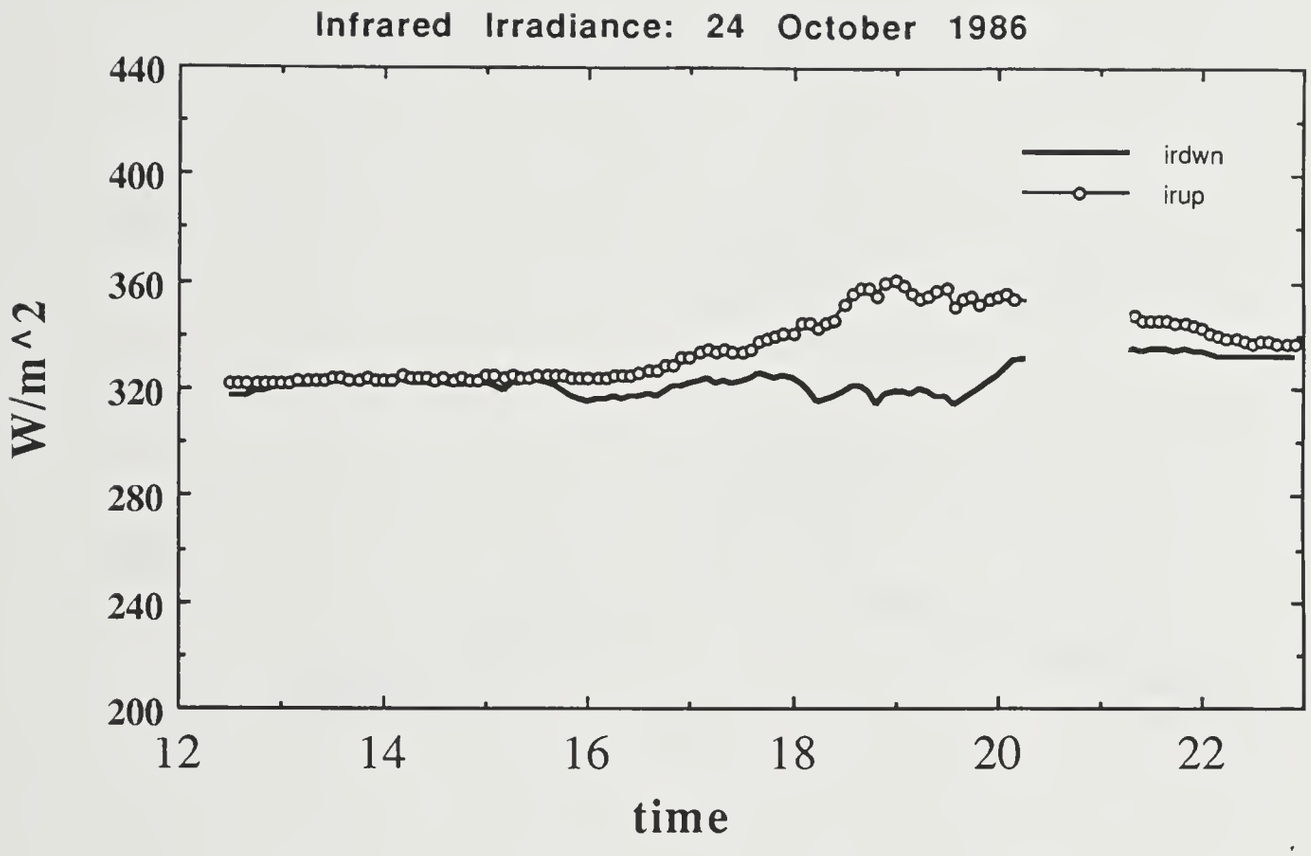
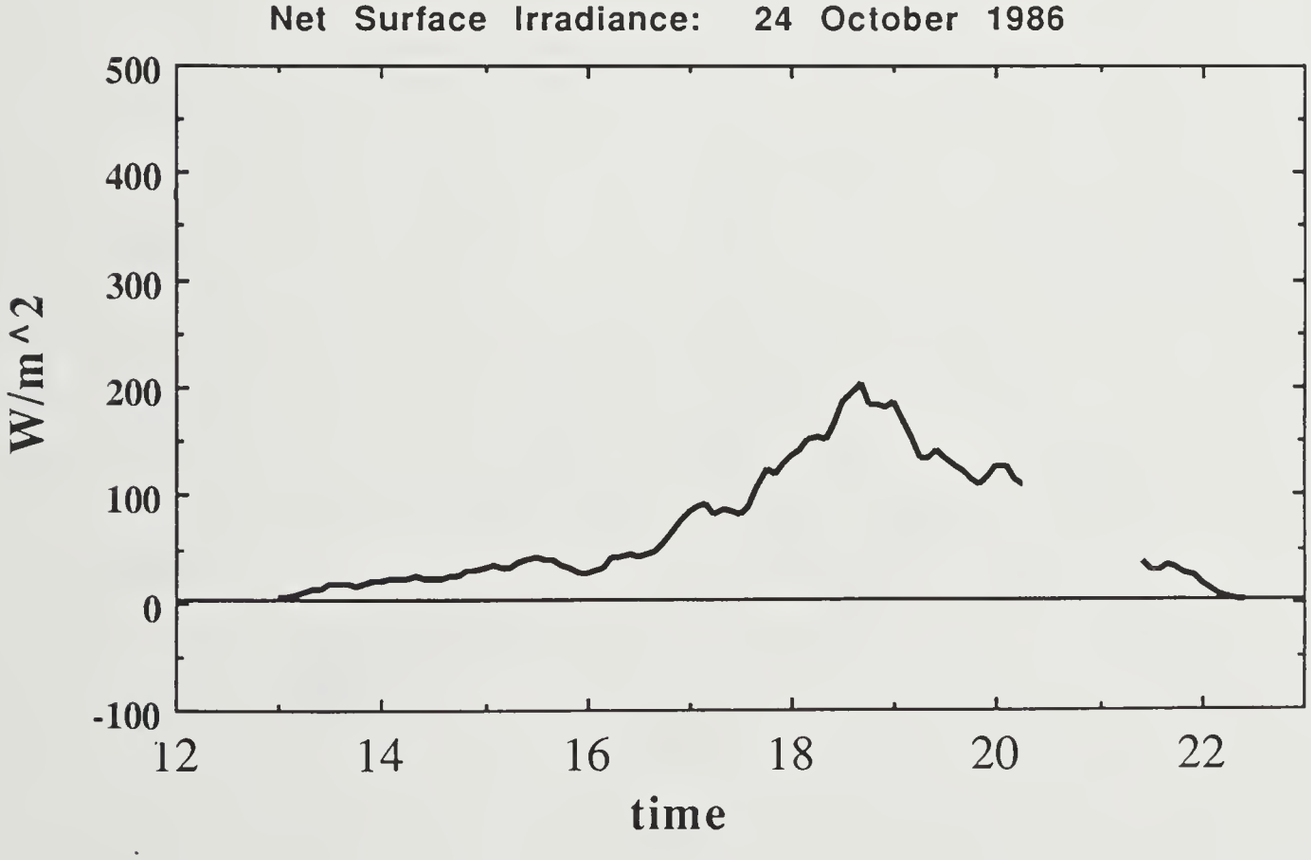
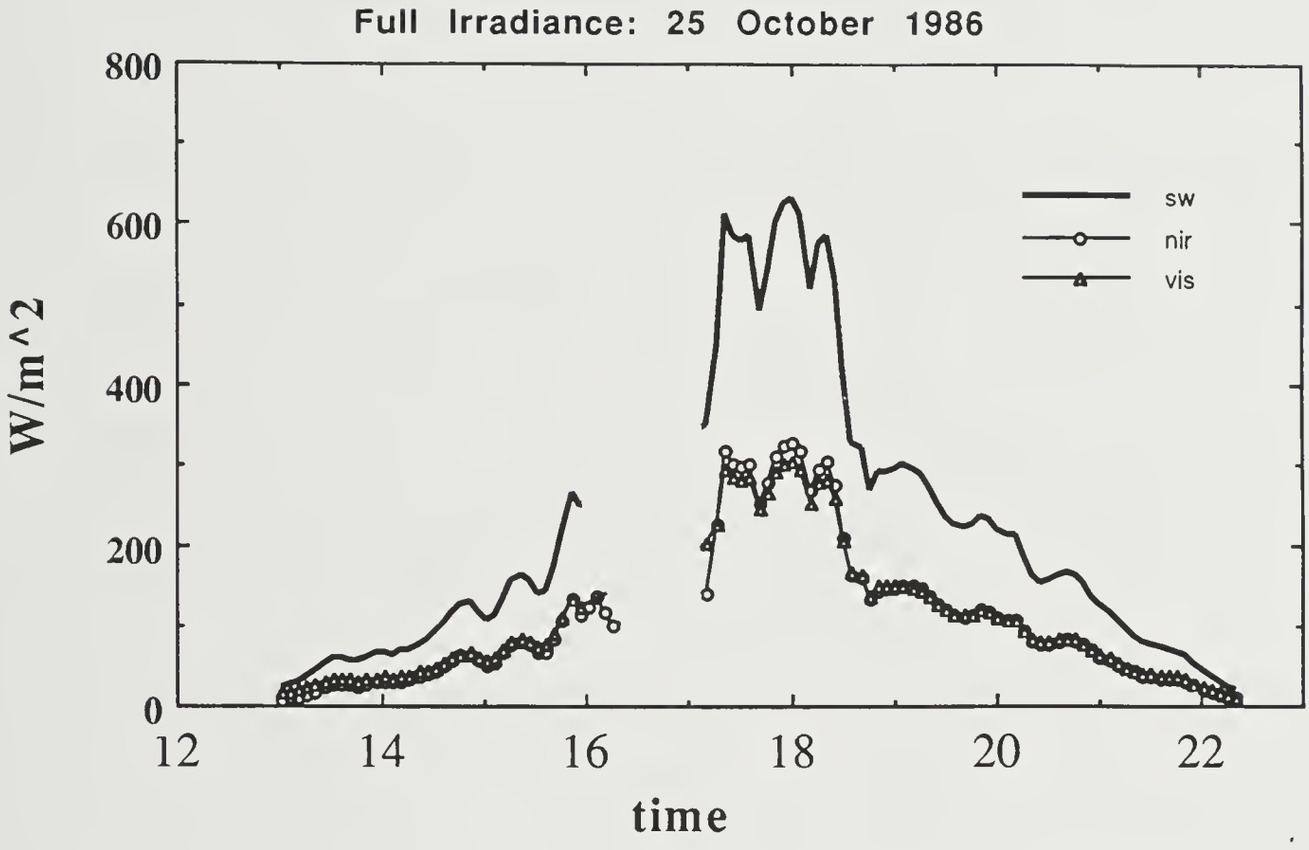
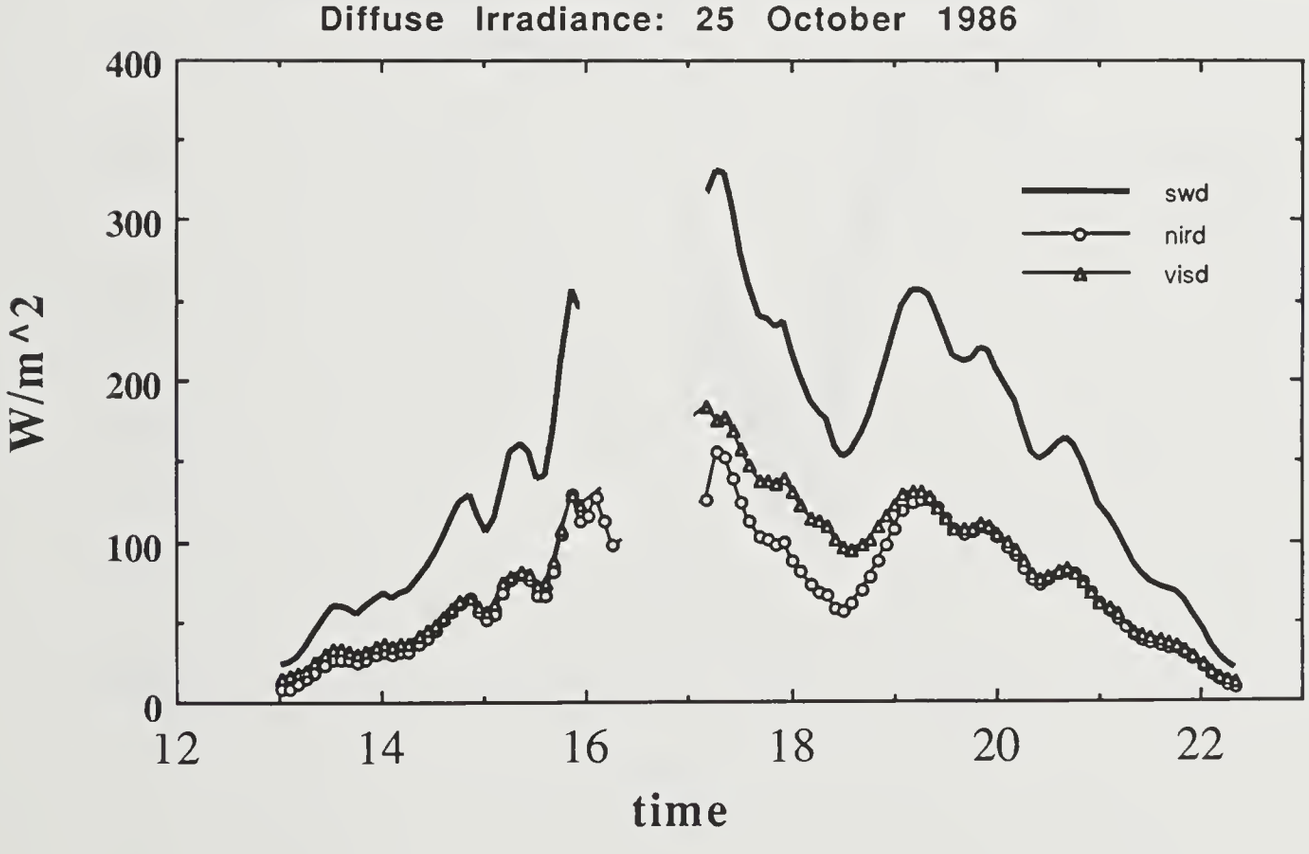
swtrans
nirtrans
vistrans

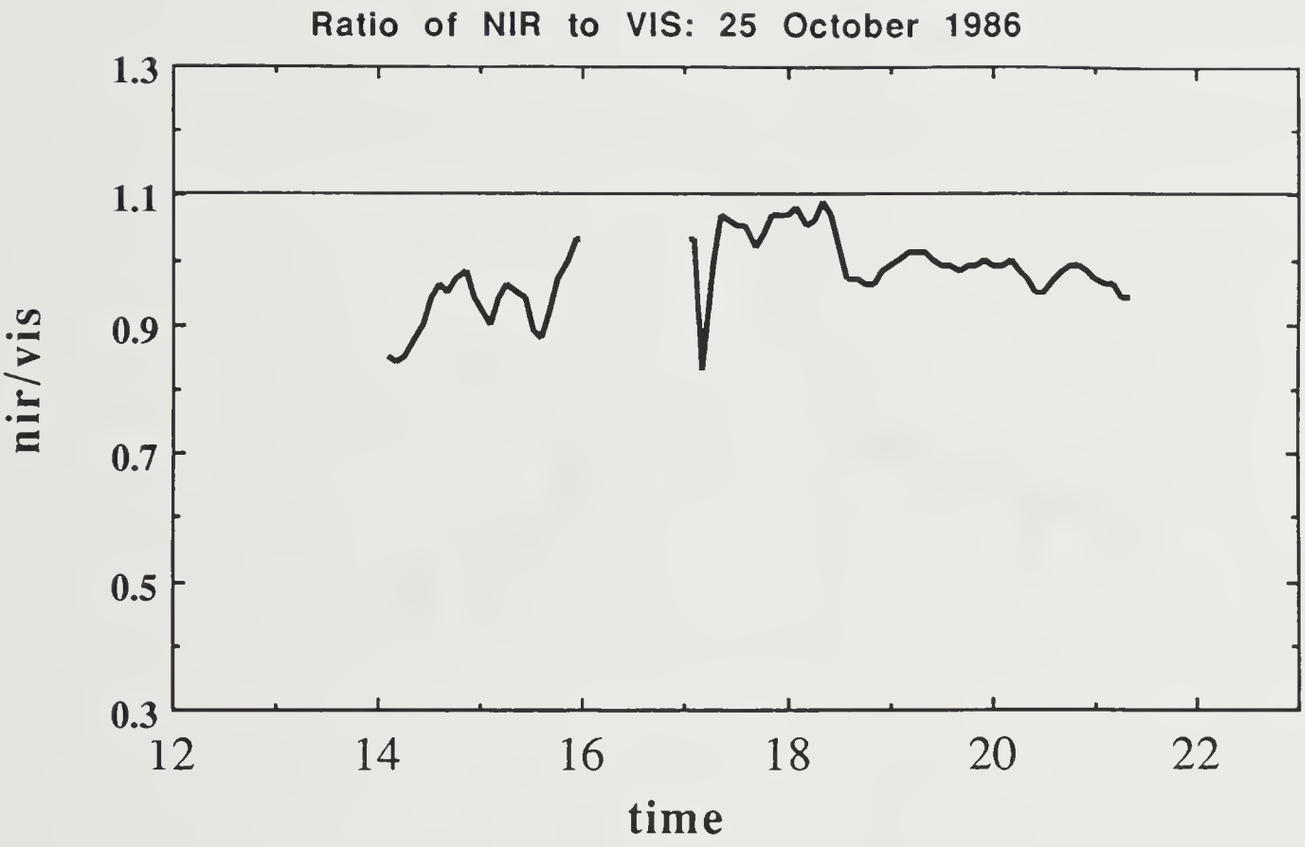

Optical Depth: 24 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep

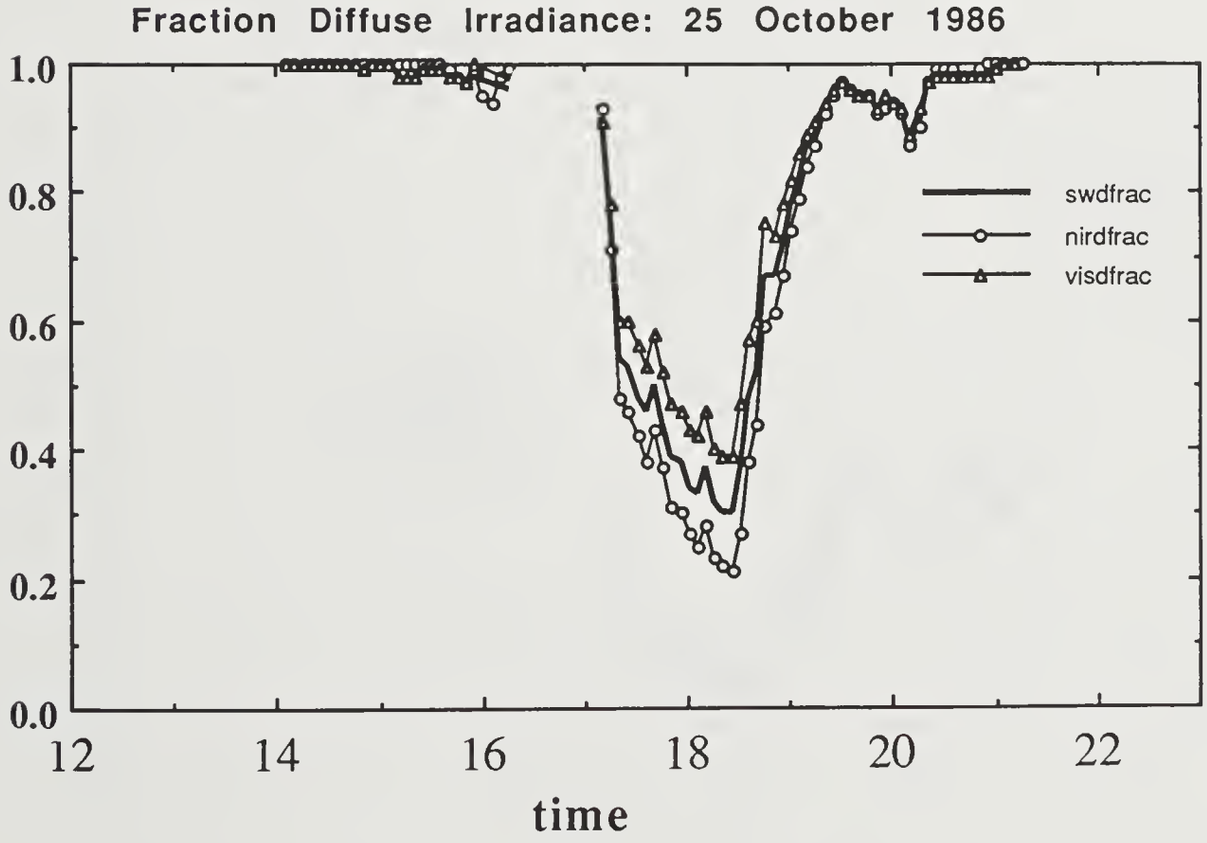

Infrared Irradiance: 24 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn
irup

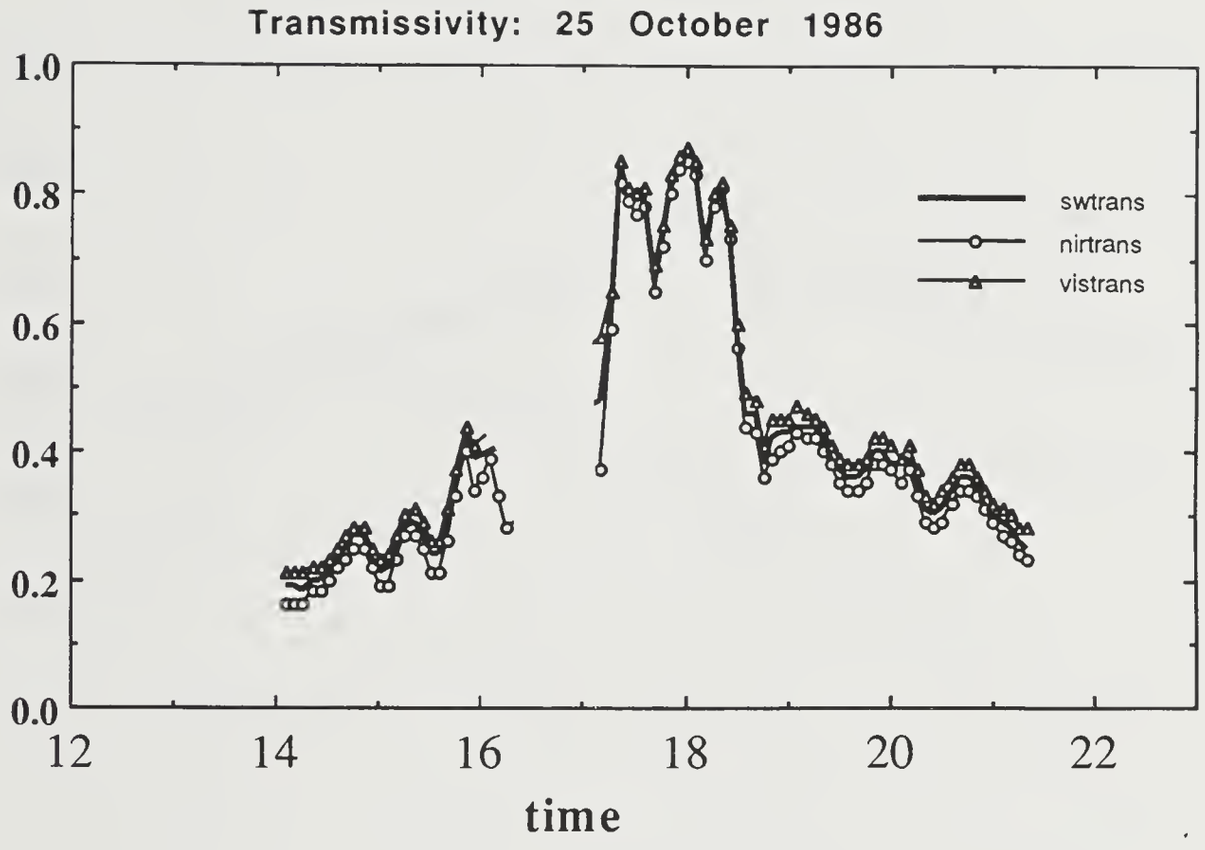

Net Surface Irradiance: 24 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time


Full Irradiance: 25 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis


Diffuse Irradiance: 25 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd


Ratio of NIR to VIS: 25 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time


Fraction Diffuse Irradiance: 25 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swdfrac
nirdfrac
visdfrac


Transmissivity: 25 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
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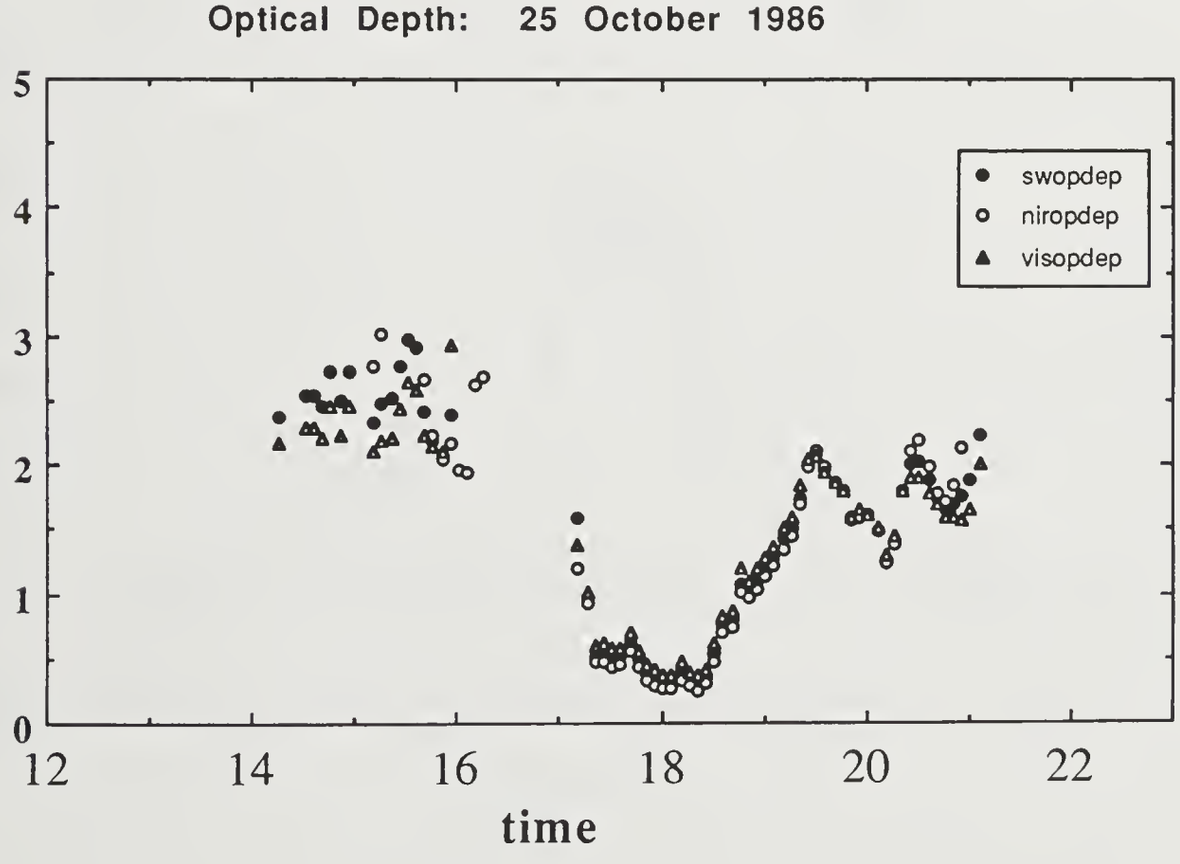
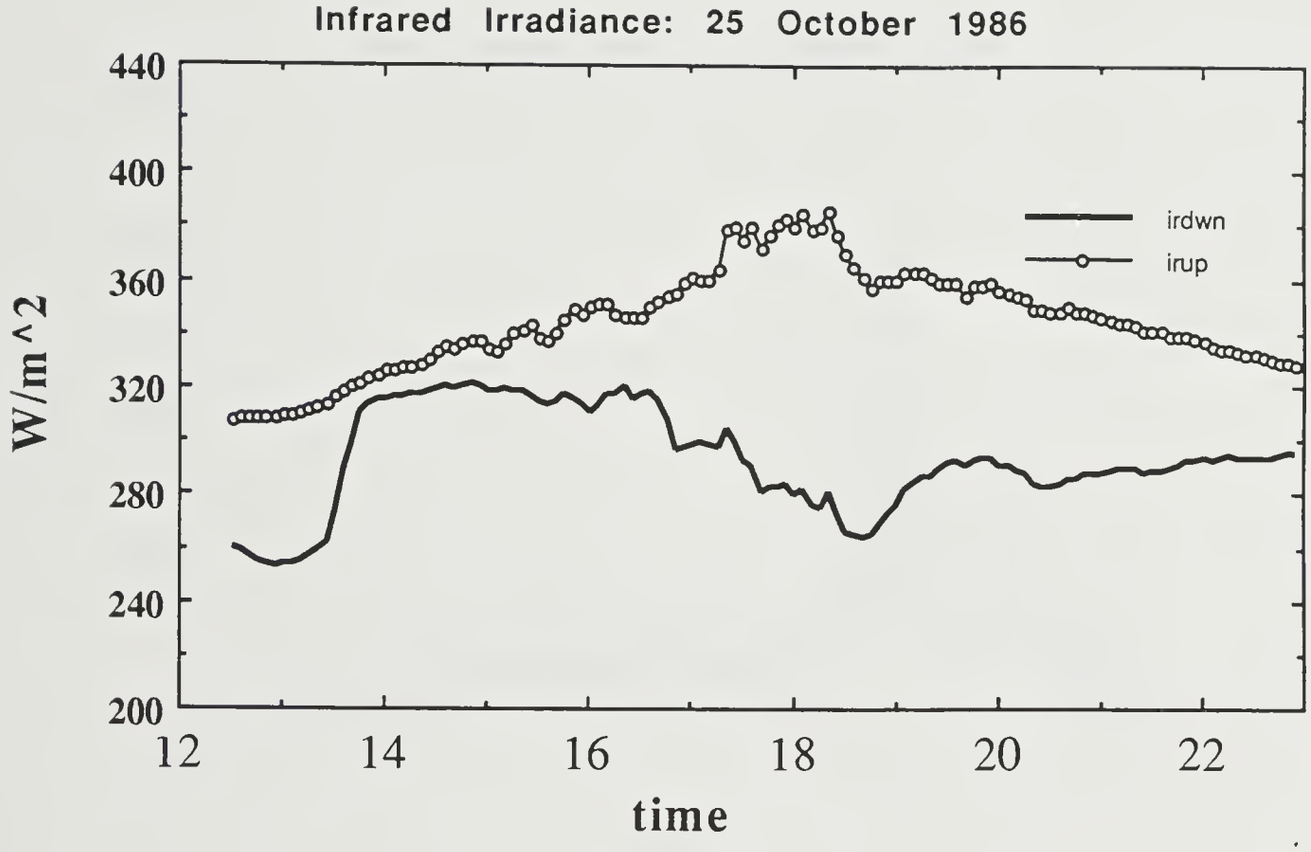
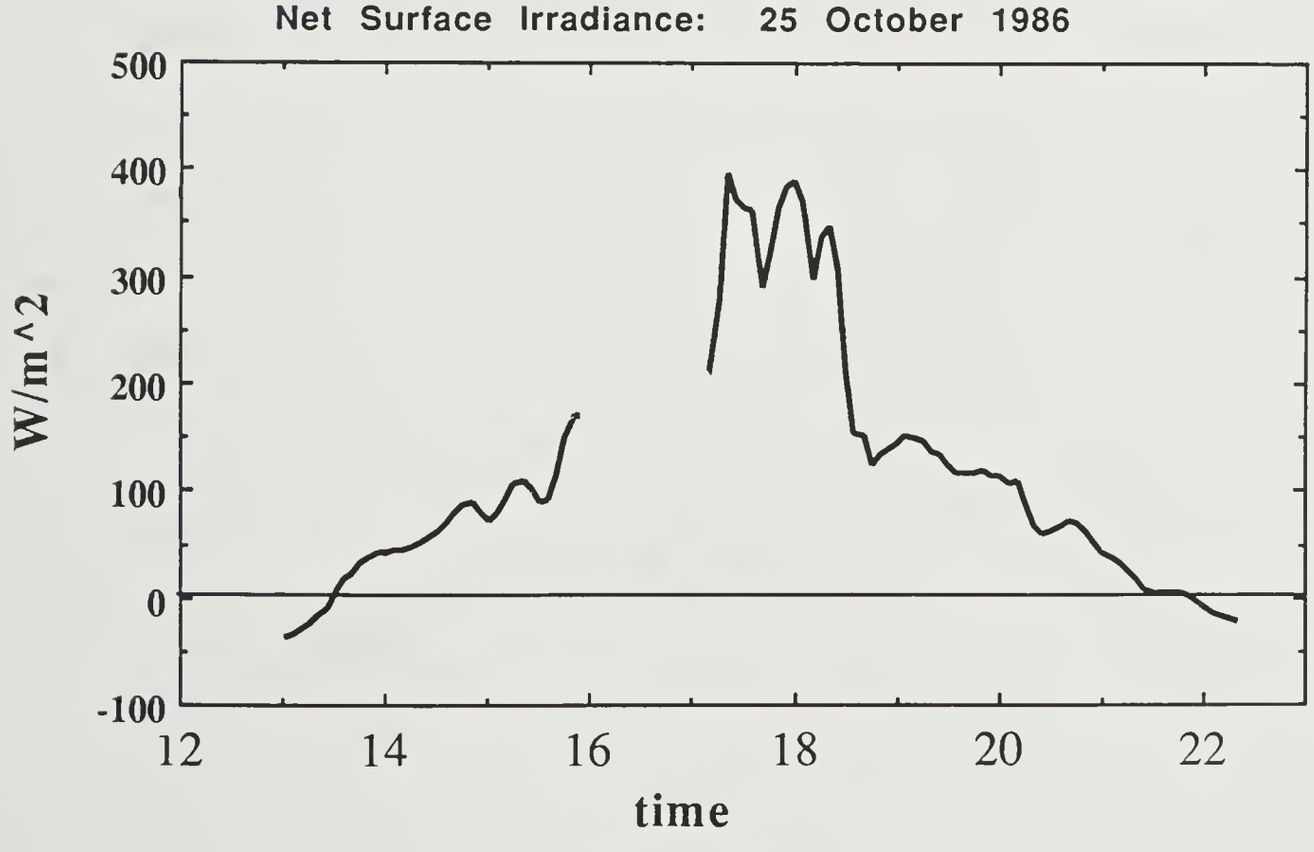
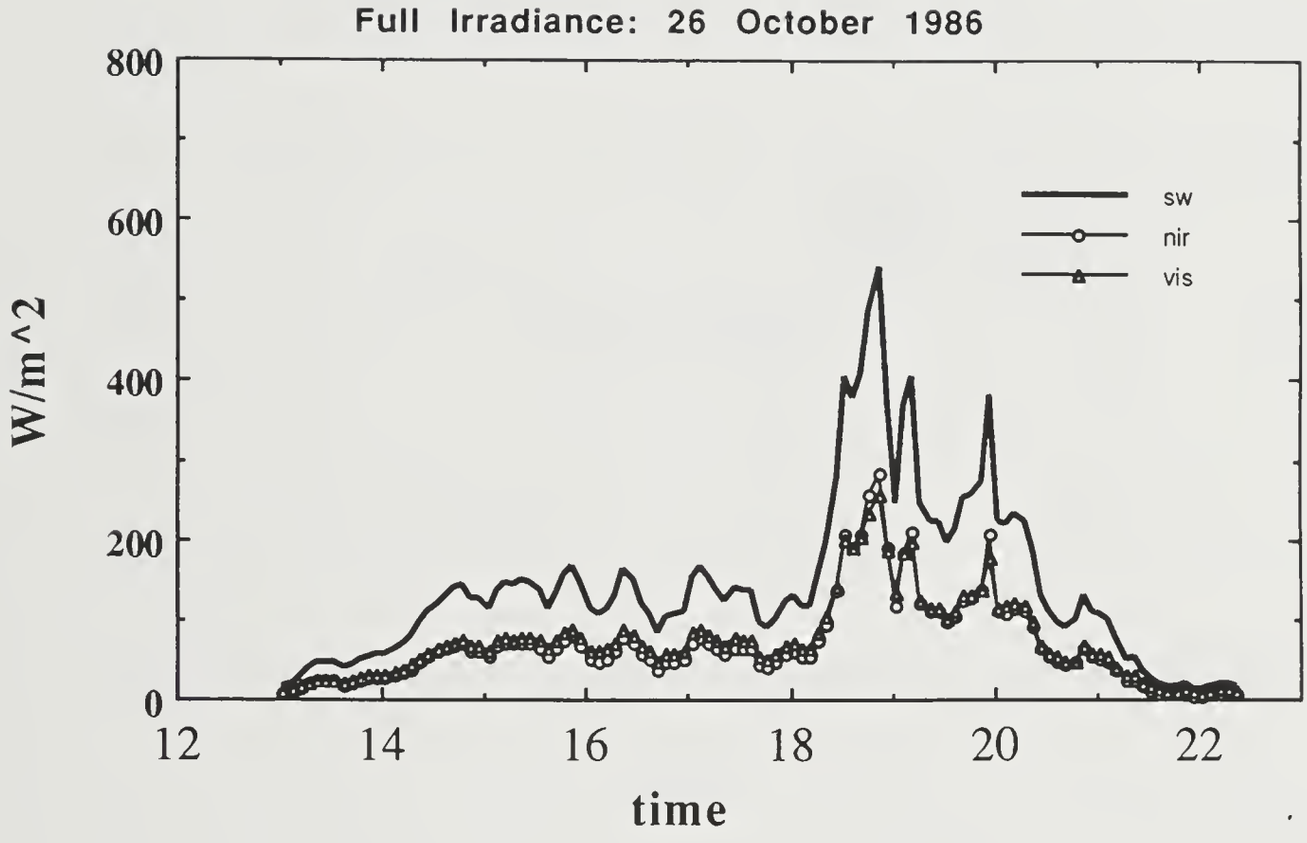
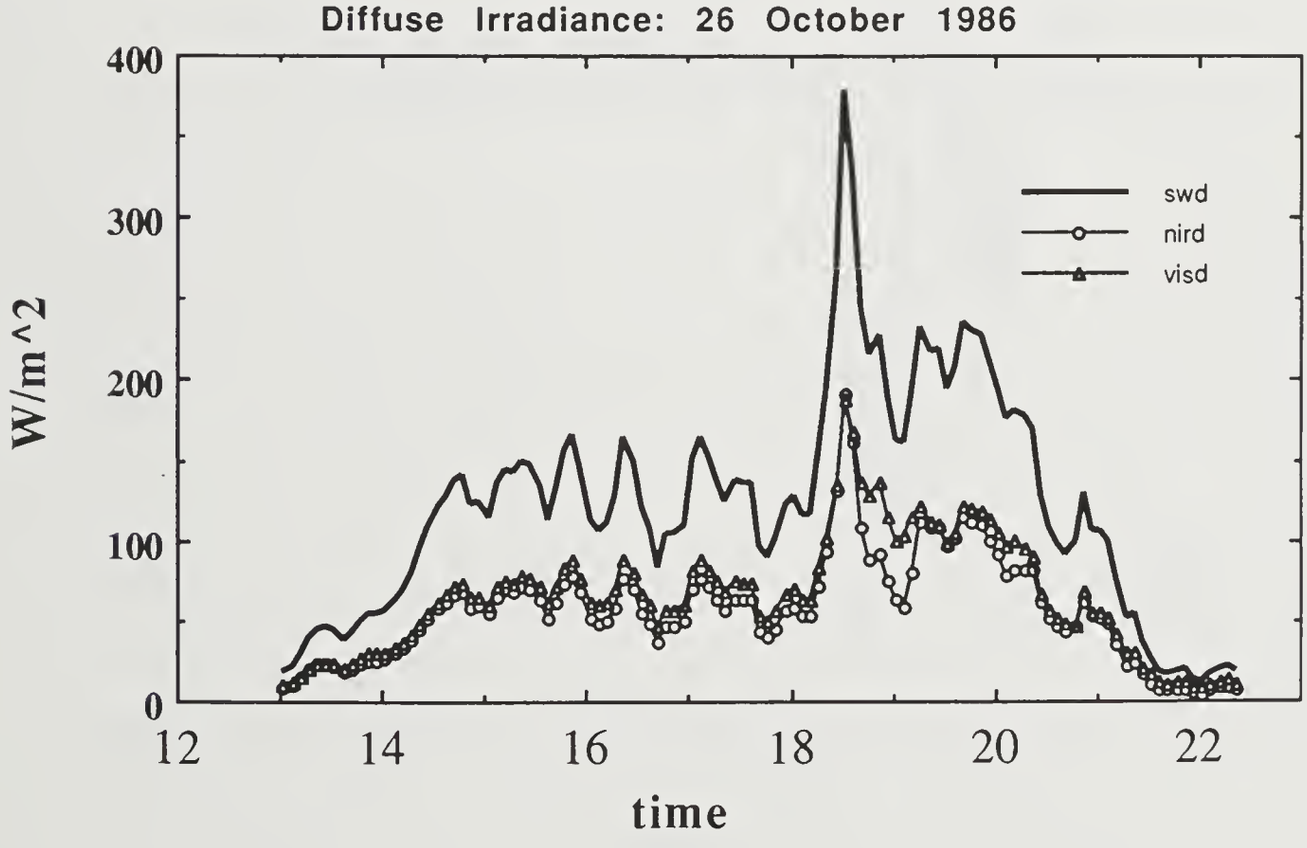
swtrans
nirtrans
vistrans

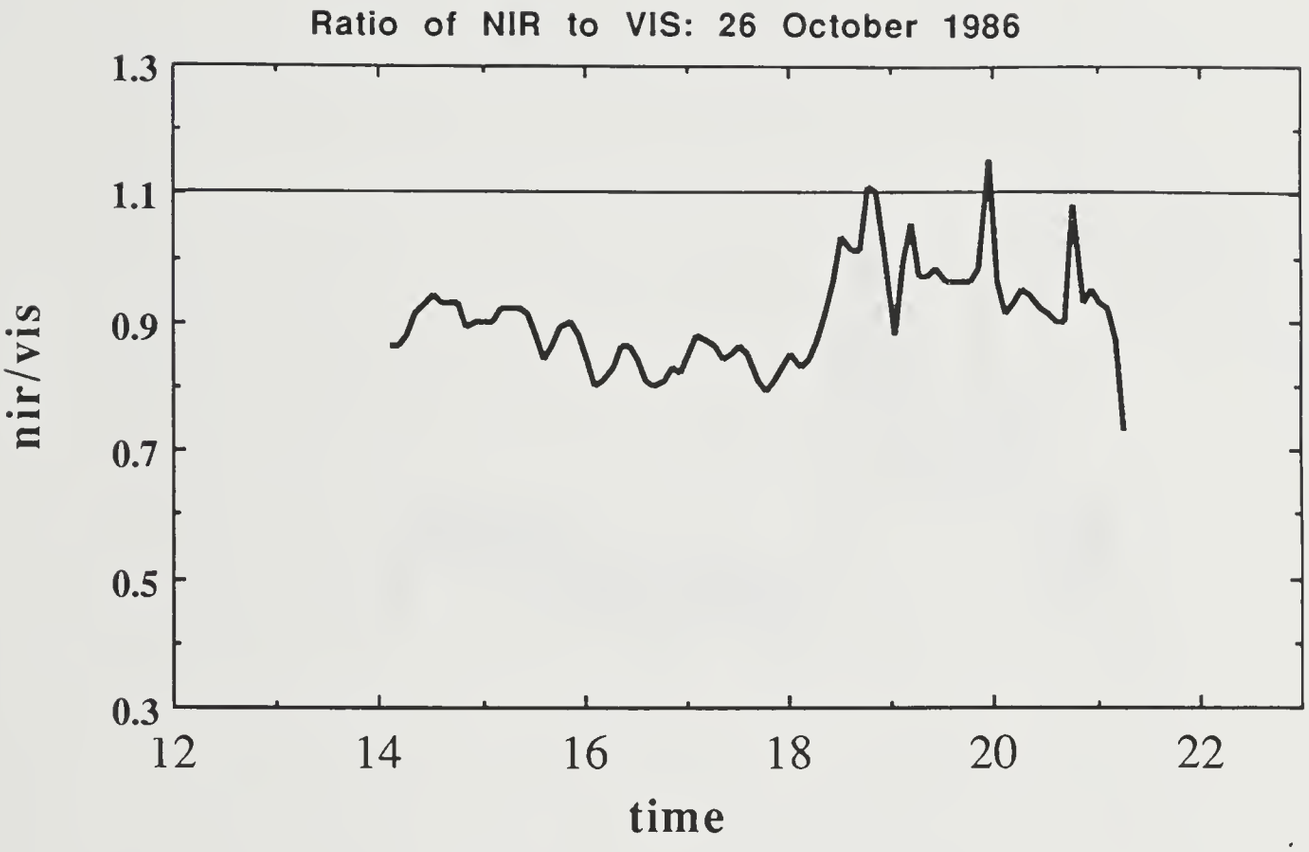

Optical Depth: 25 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep
niropdep
visopdep

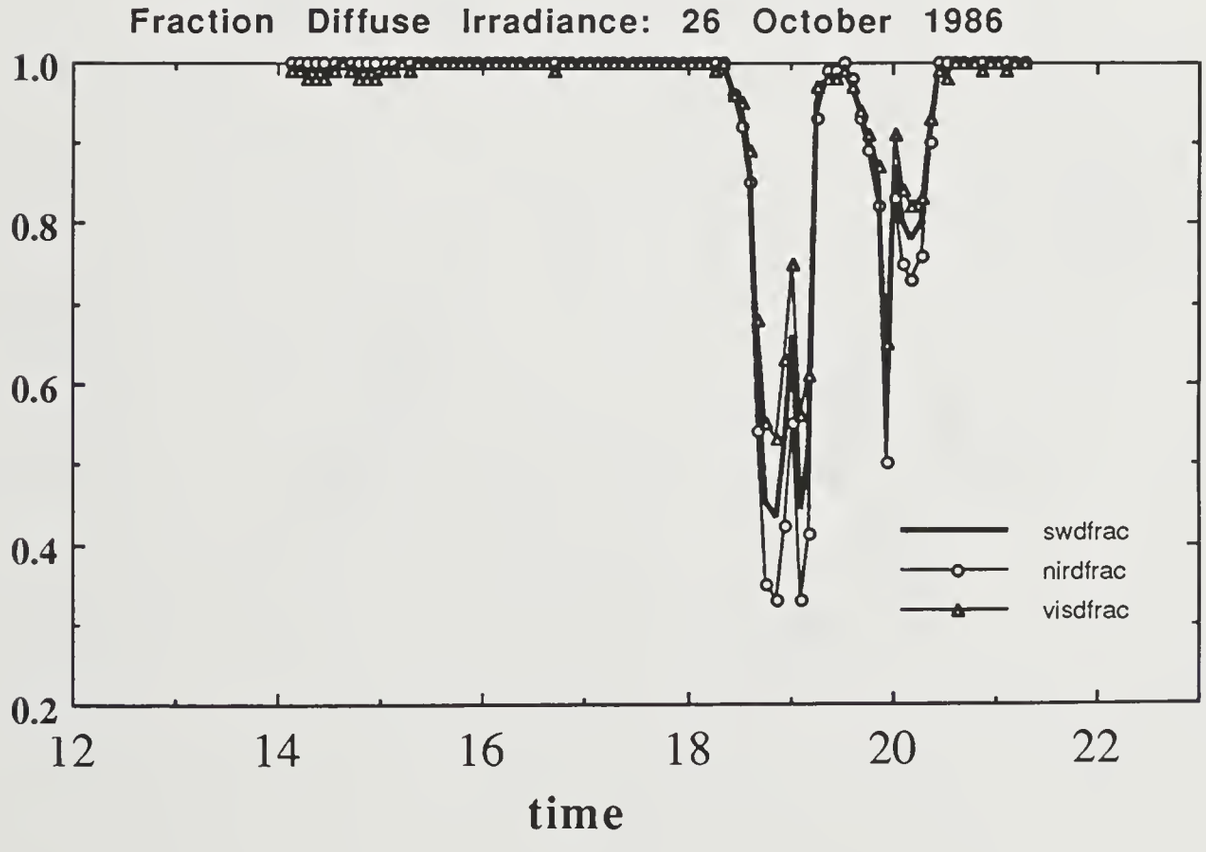

Infrared Irradiance: 25 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn
irup


Net Surface Irradiance: 25 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time


Full Irradiance: 26 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis


Diffuse Irradiance: 26 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd


Ratio of NIR to VIS: 26 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time


Fraction Diffuse Irradiance: 26 October 1986
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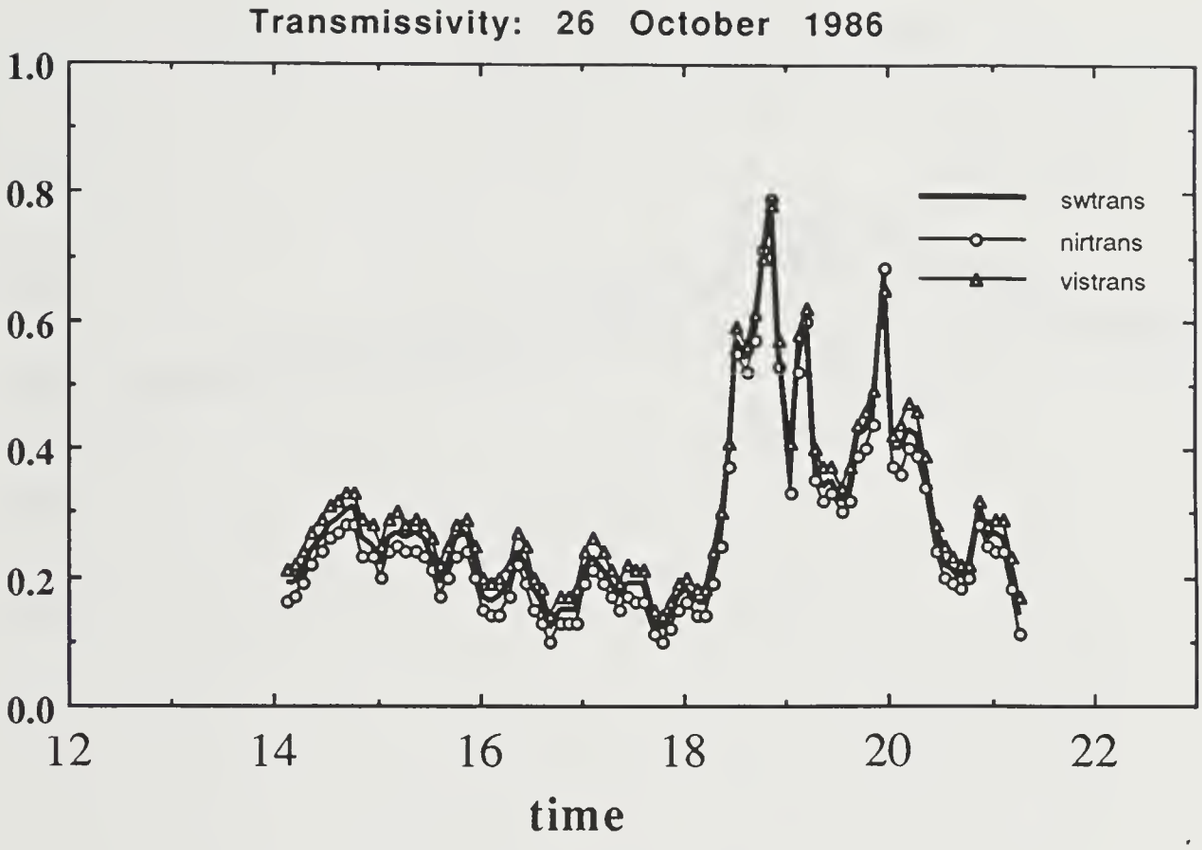
0.6
0.4
0.2
12
14
16
18
20
22
time
swdfrac
nirdfrac
visdfrac


Transmissivity: 26 October 1986
1.0
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0.4
0.2
0.0
12
14
16
18
20
22
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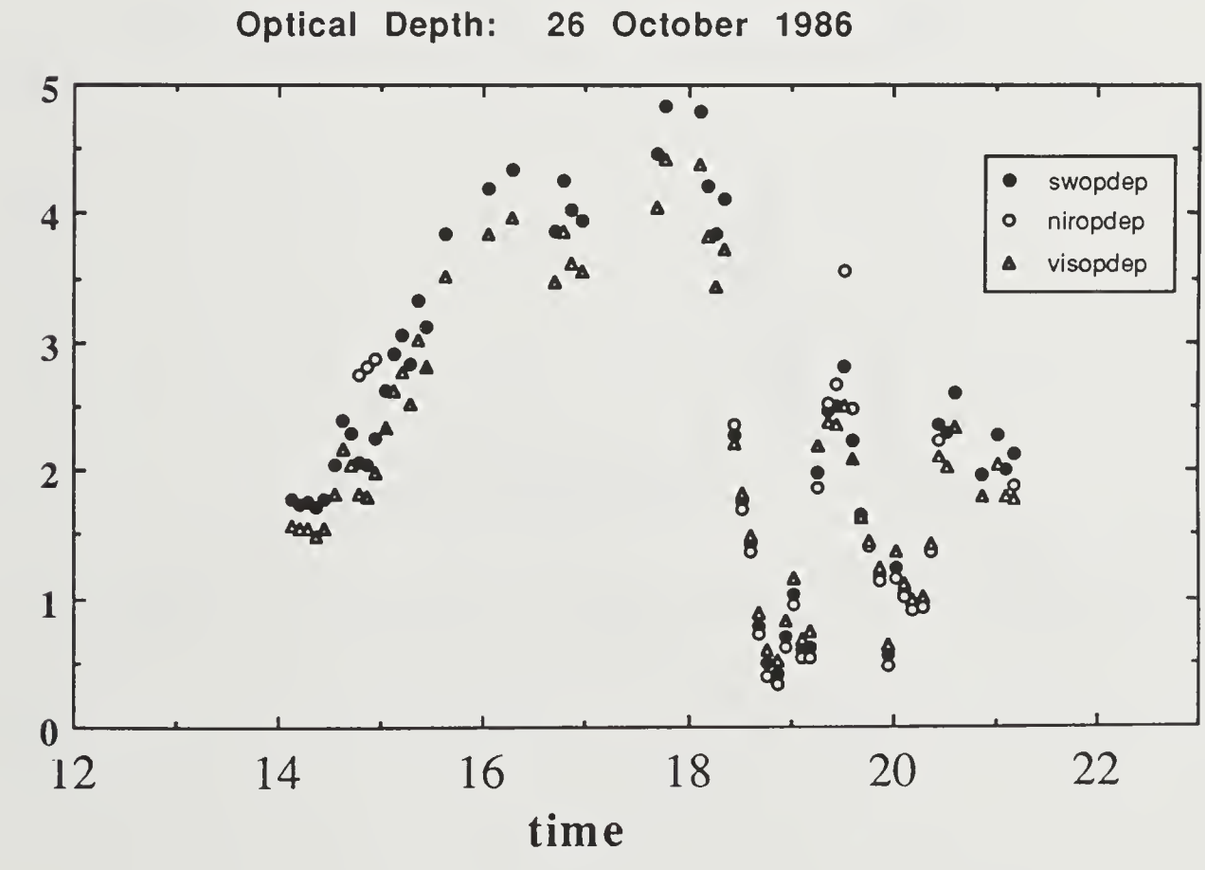
swtrans
nirtrans
vistrans


Optical Depth: 26 October 1986
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12
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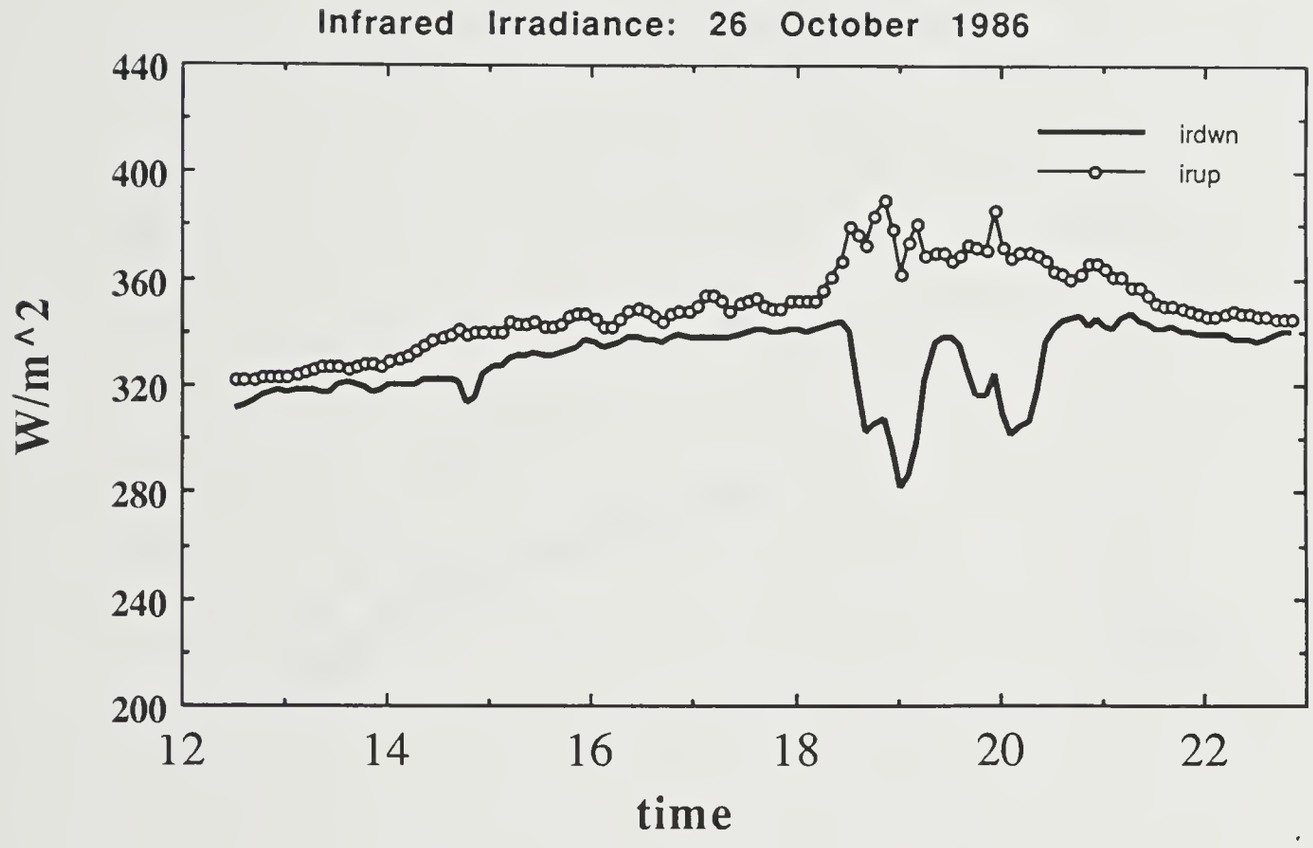
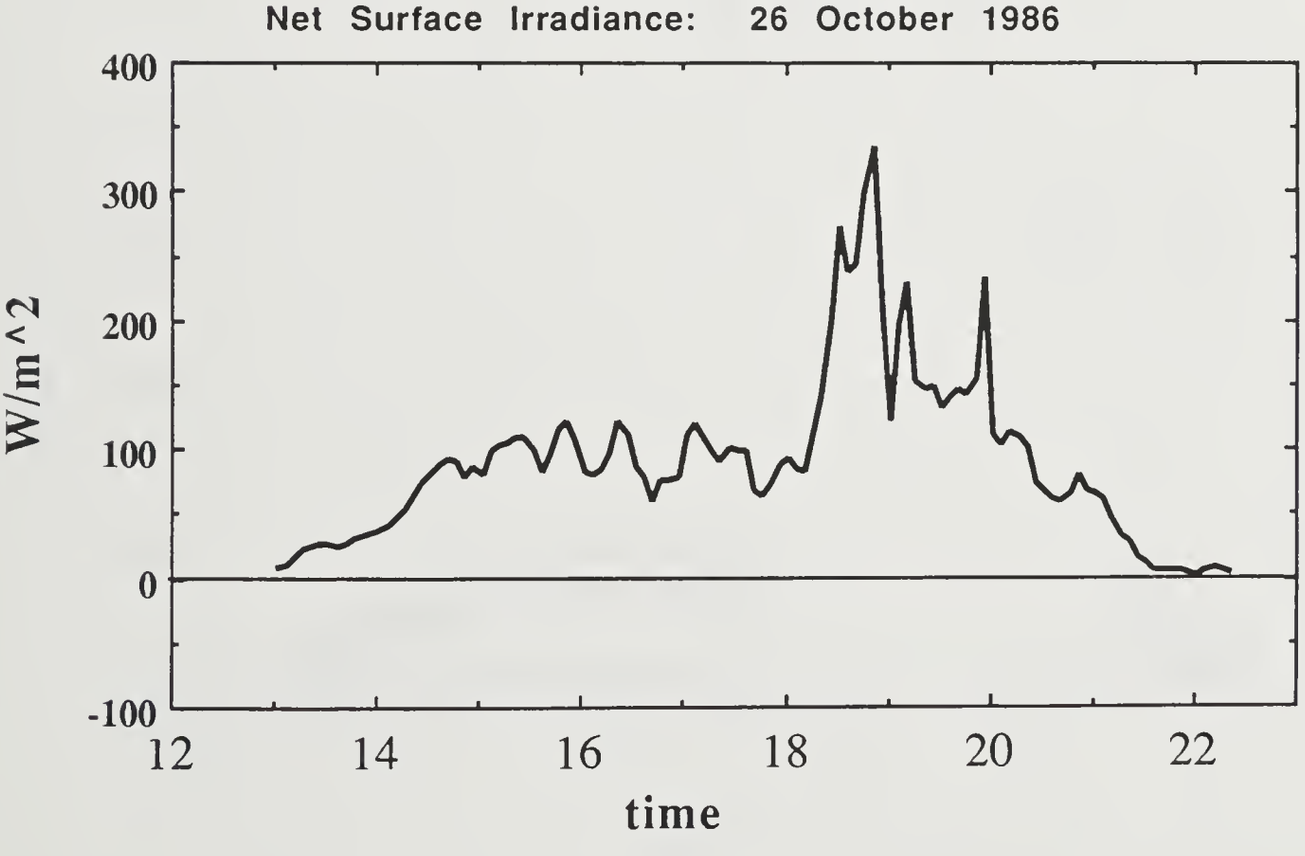
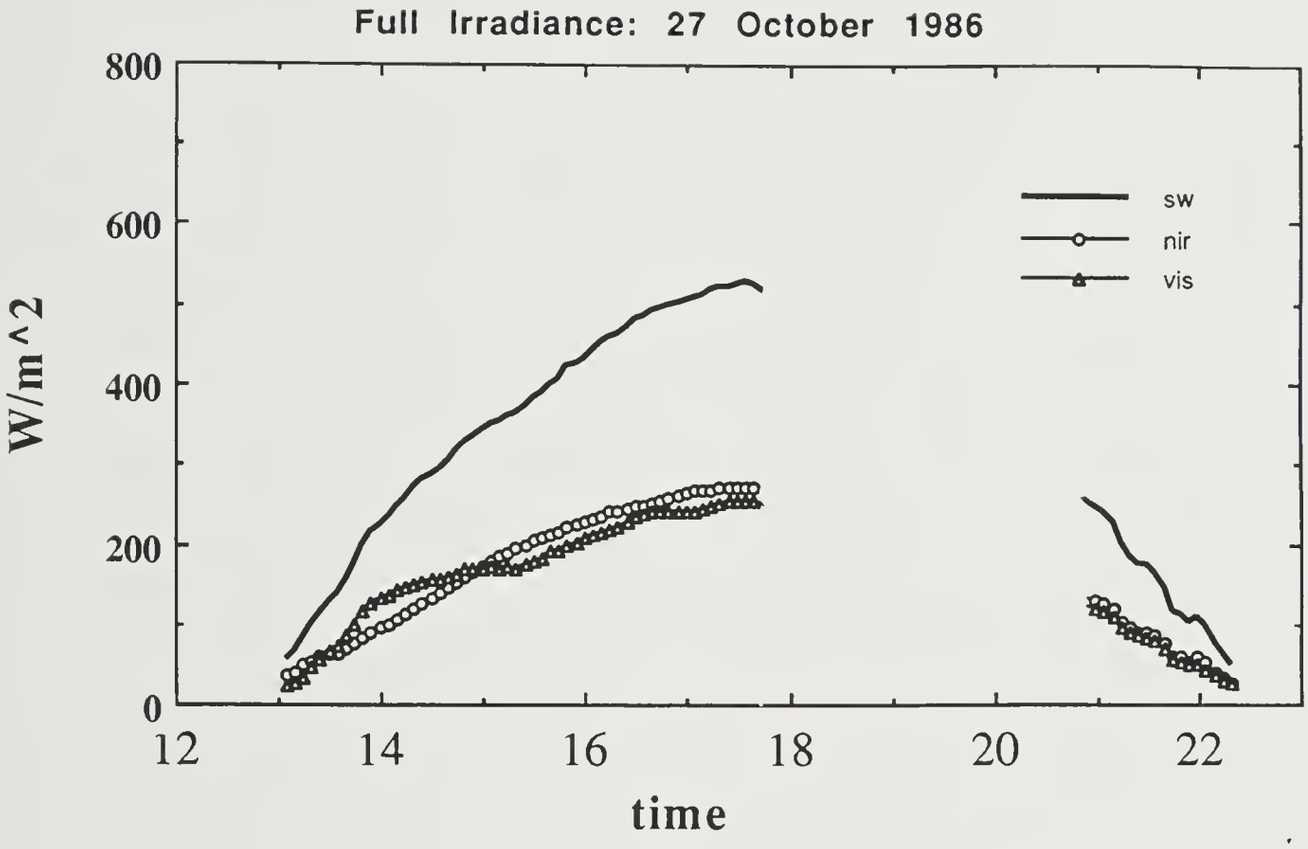
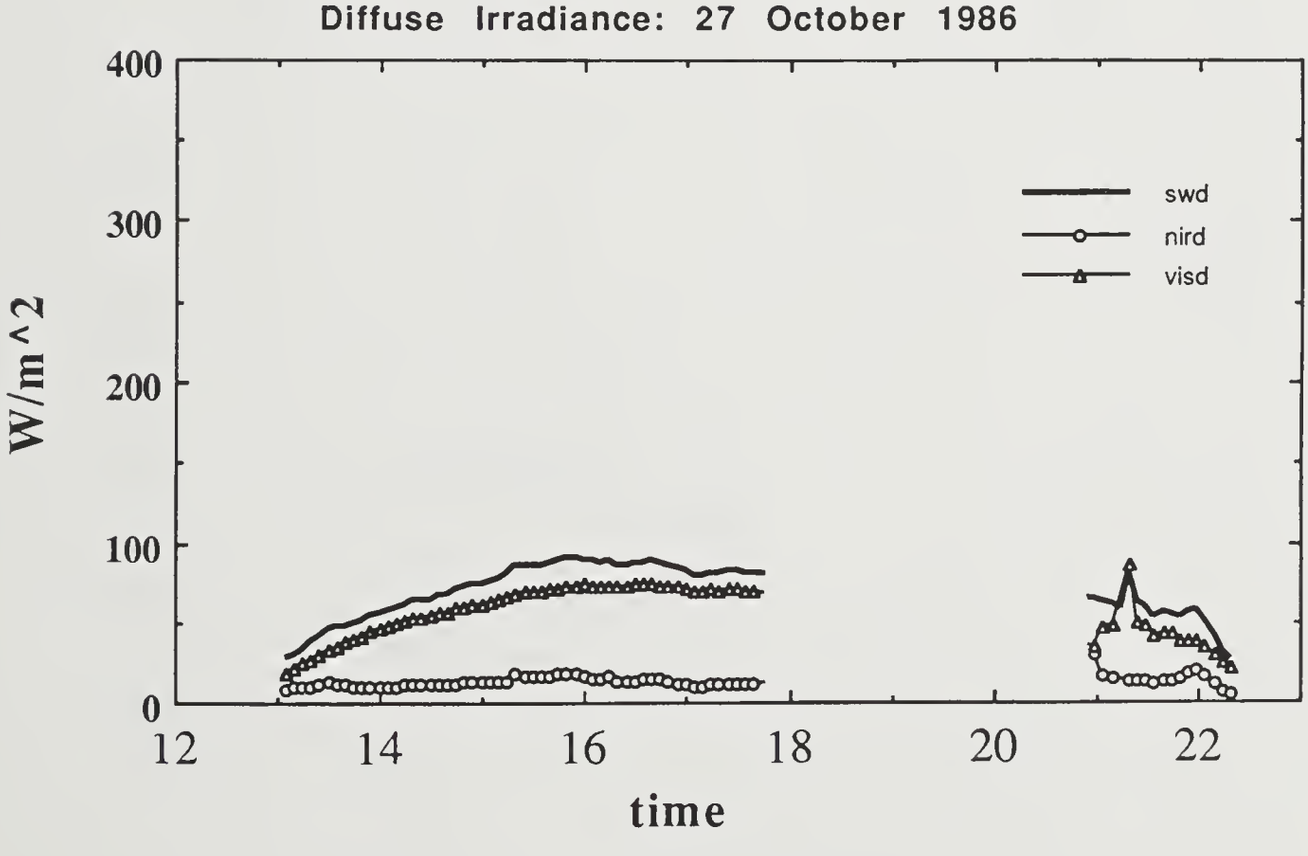
18
20
22
time
swopdep
niropdep
visopdep


Infrared Irradiance: 26 October 1986
440
400
360
320
280
240
200
W/m^2
irdwn
irup
12
14
16
18
20
22
time


Net Surface Irradiance: 26 October 1986
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time


Full Irradiance: 27 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis


Diffuse Irradiance: 27 October 1986
400
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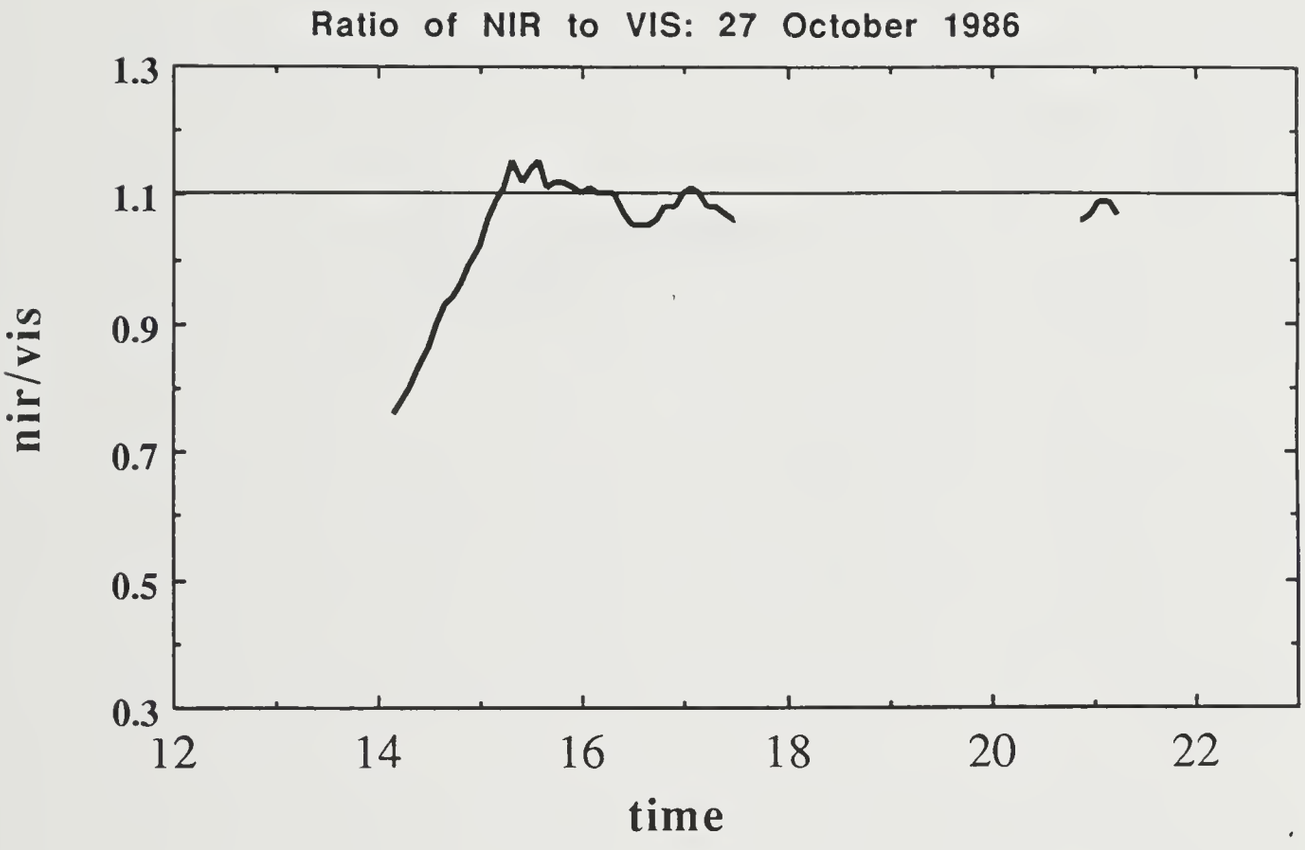
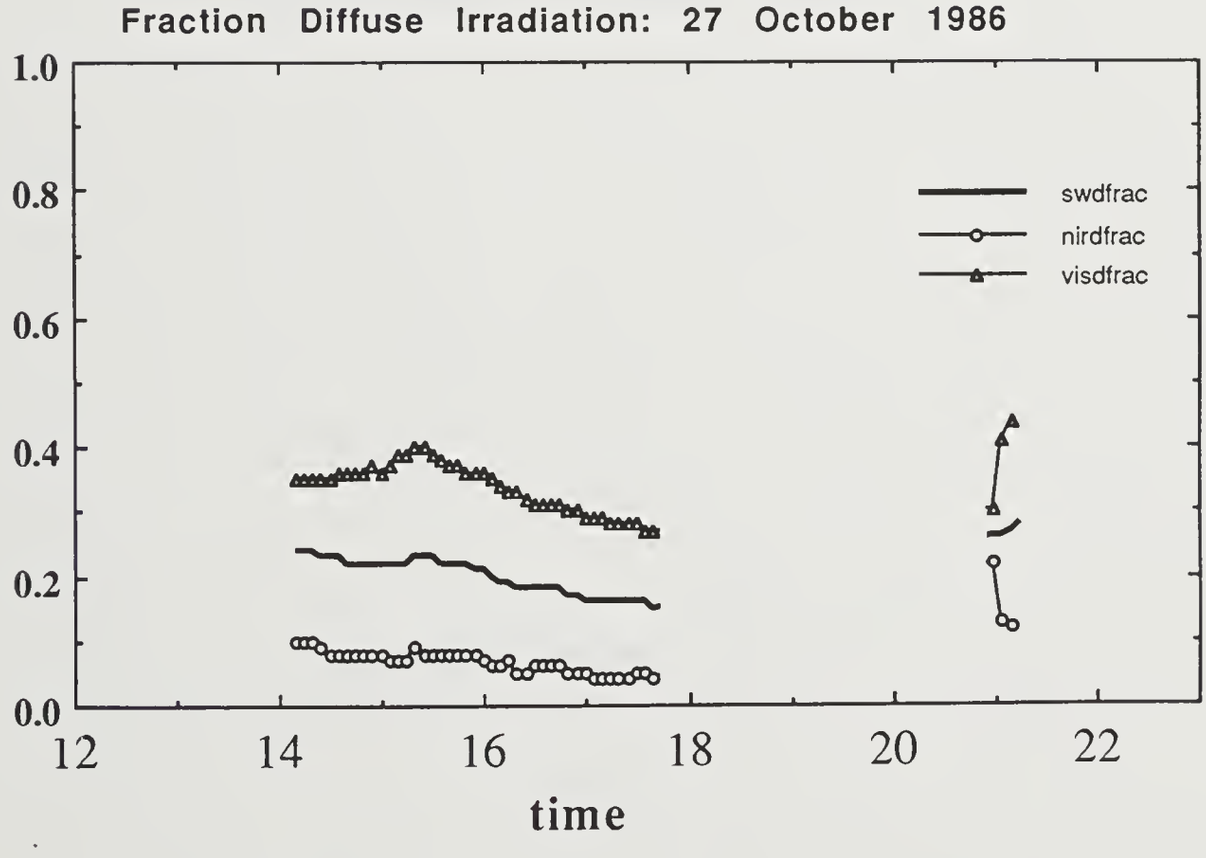
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd


Ratio of NIR to VIS: 27 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time


Fraction Diffuse Irradiation: 27 October 1986
1.0
0.8
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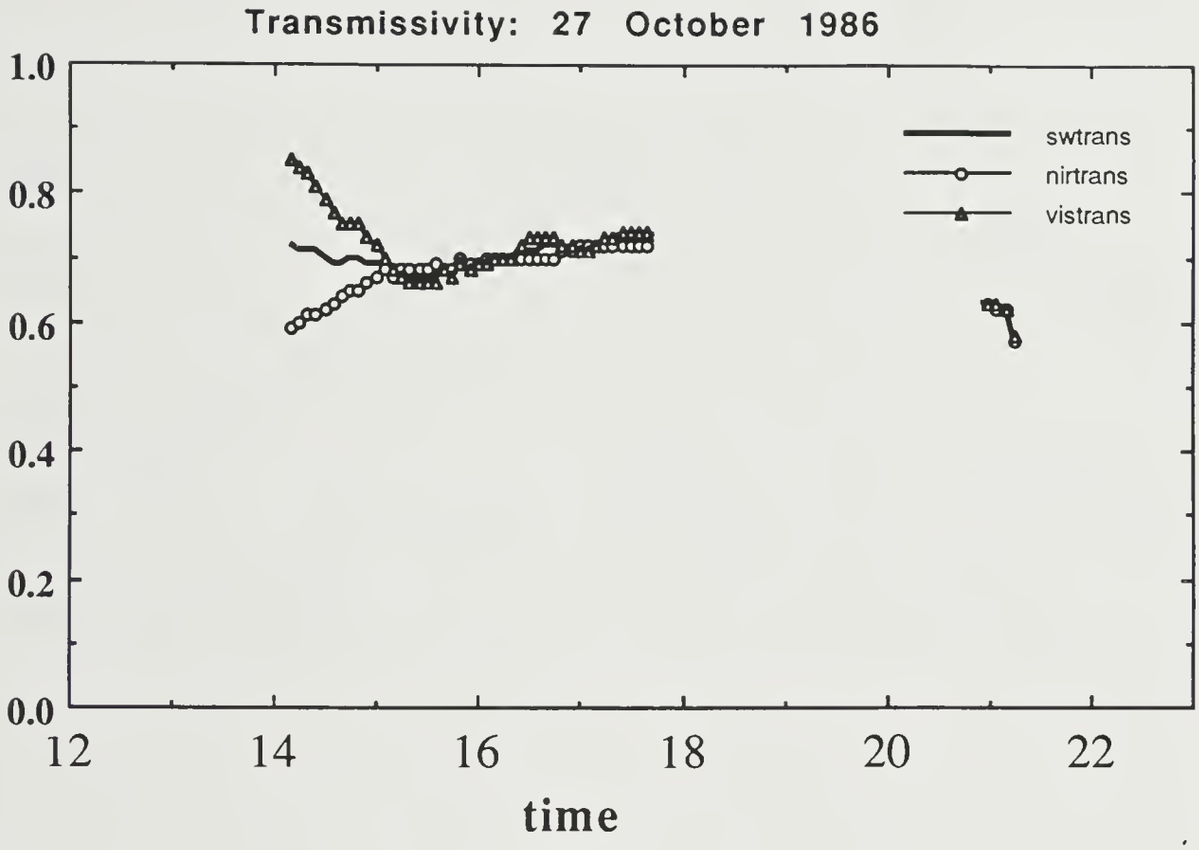
0.4
0.2
0.0
swdfrac
nirdfrac
visdfrac
12
14
16
18
20
22
time


Transmissivity: 27 October 1986
1.0
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0.2
0.0
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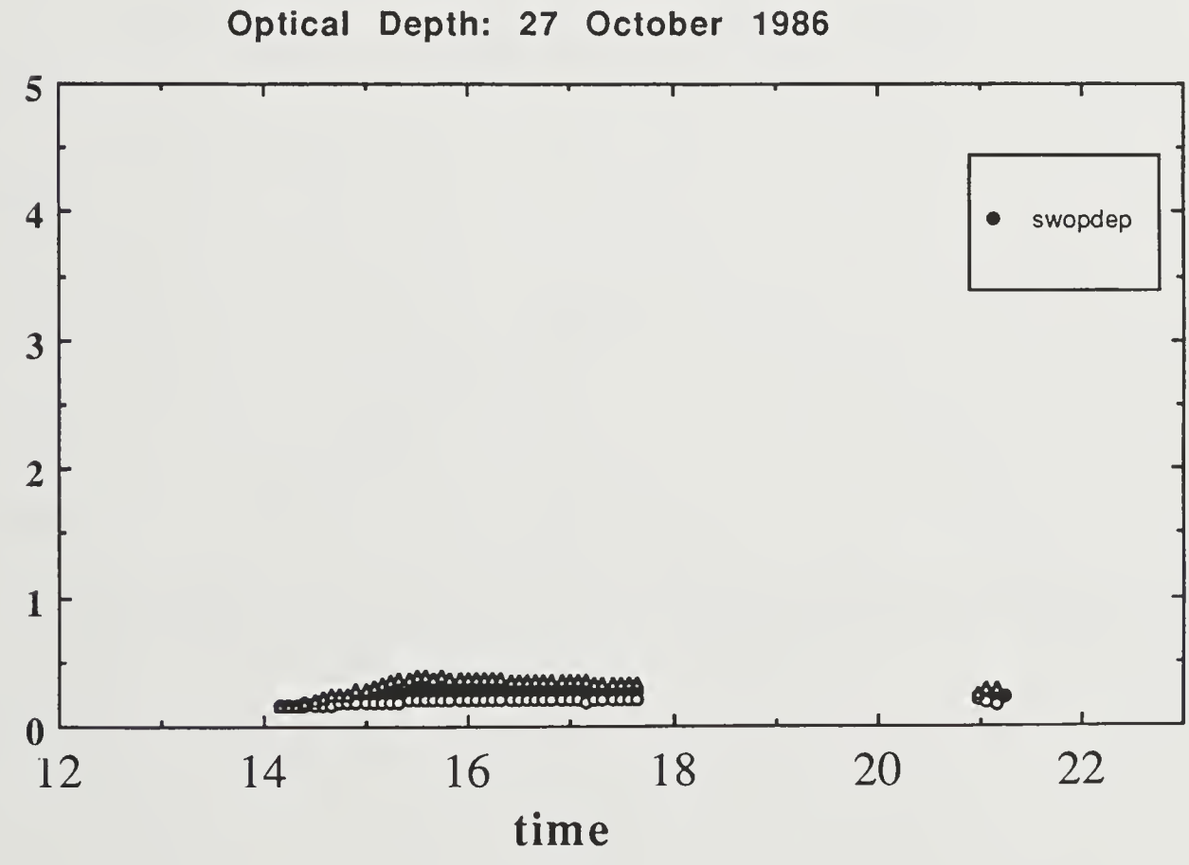
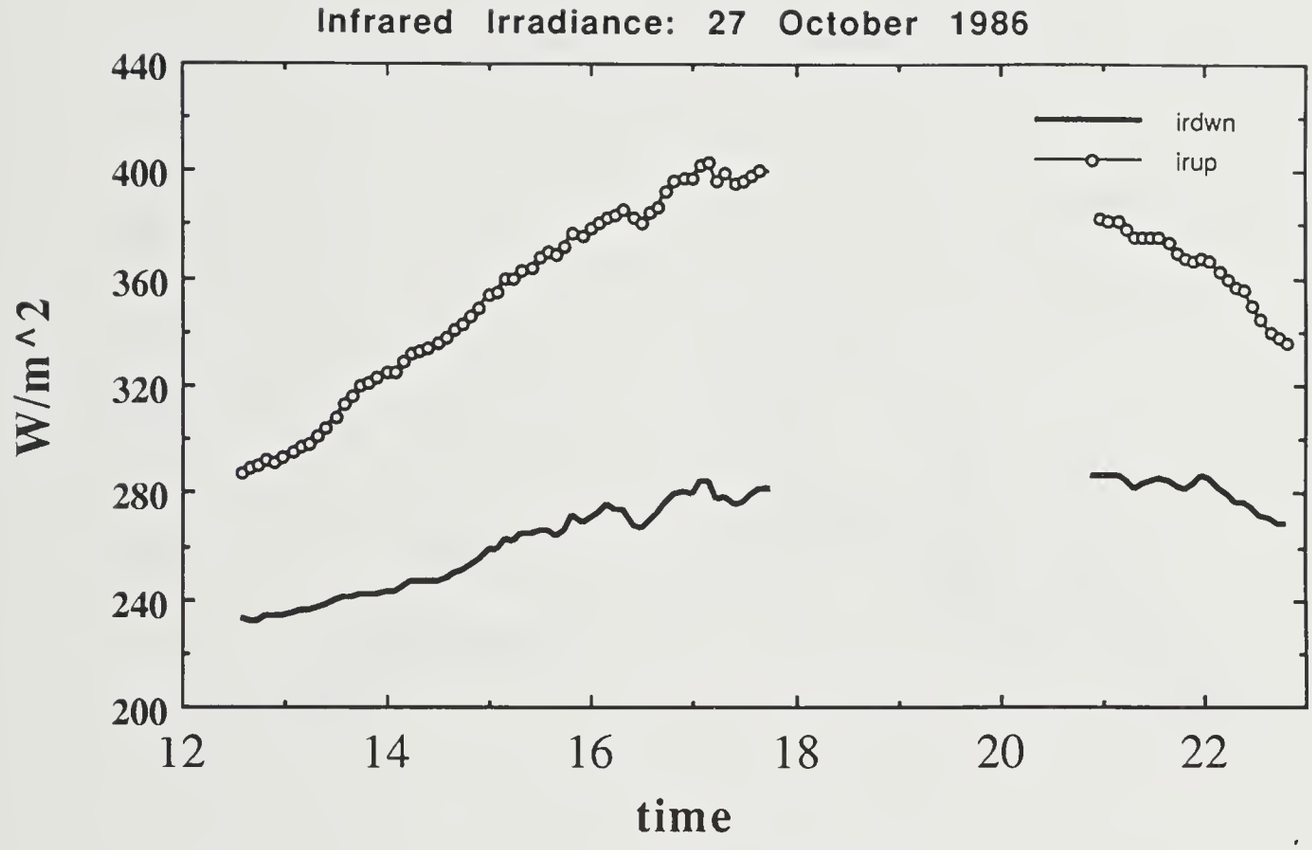
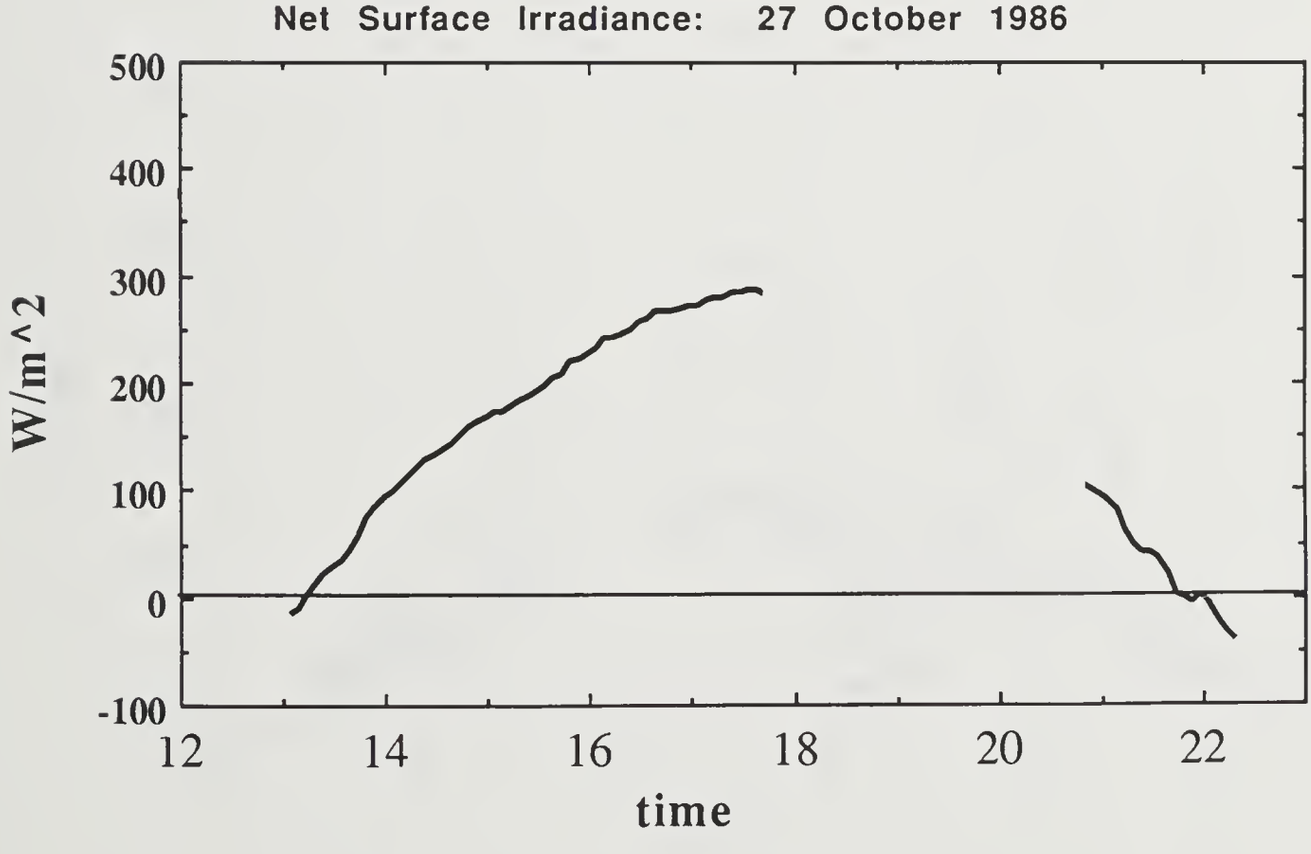
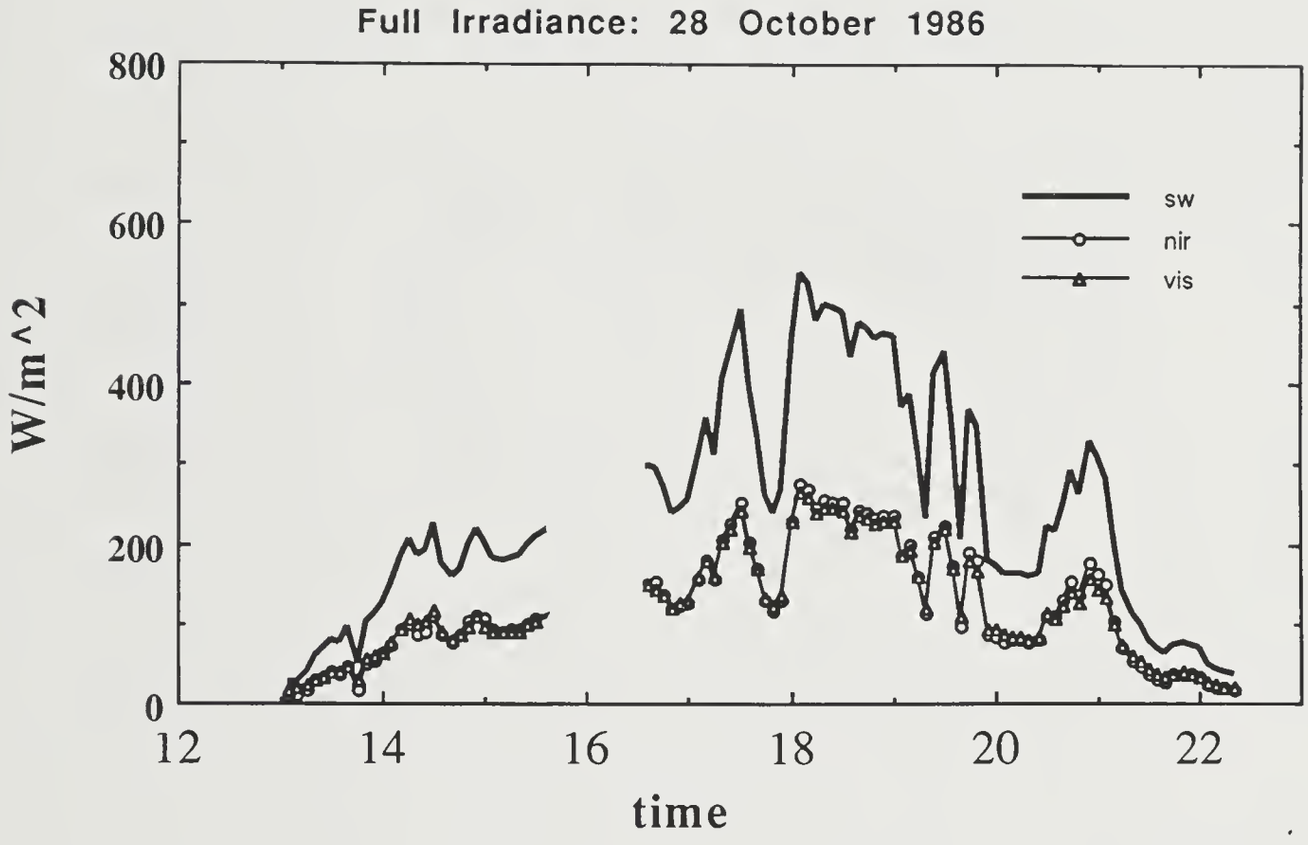
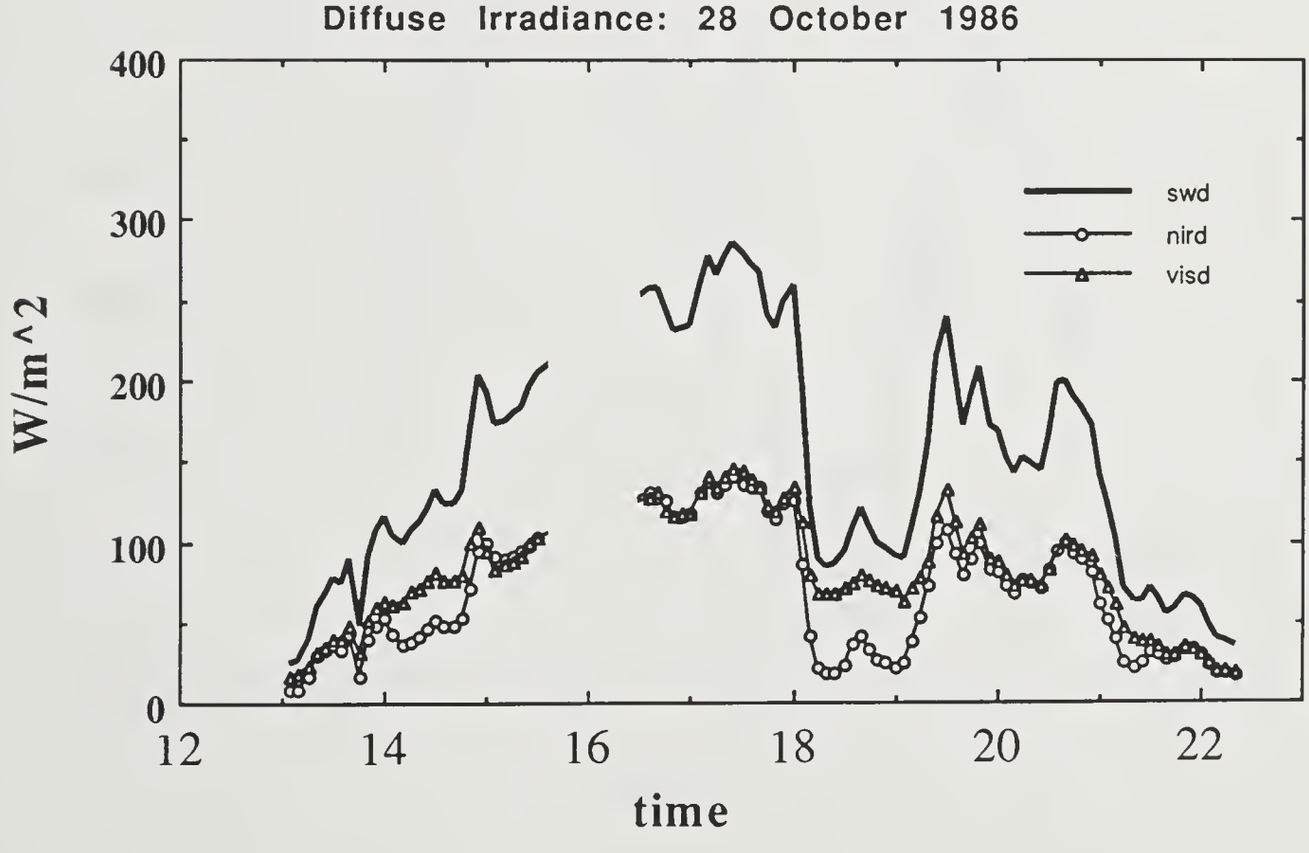
18
20
22
time
swtrans
nirtrans
vistrans

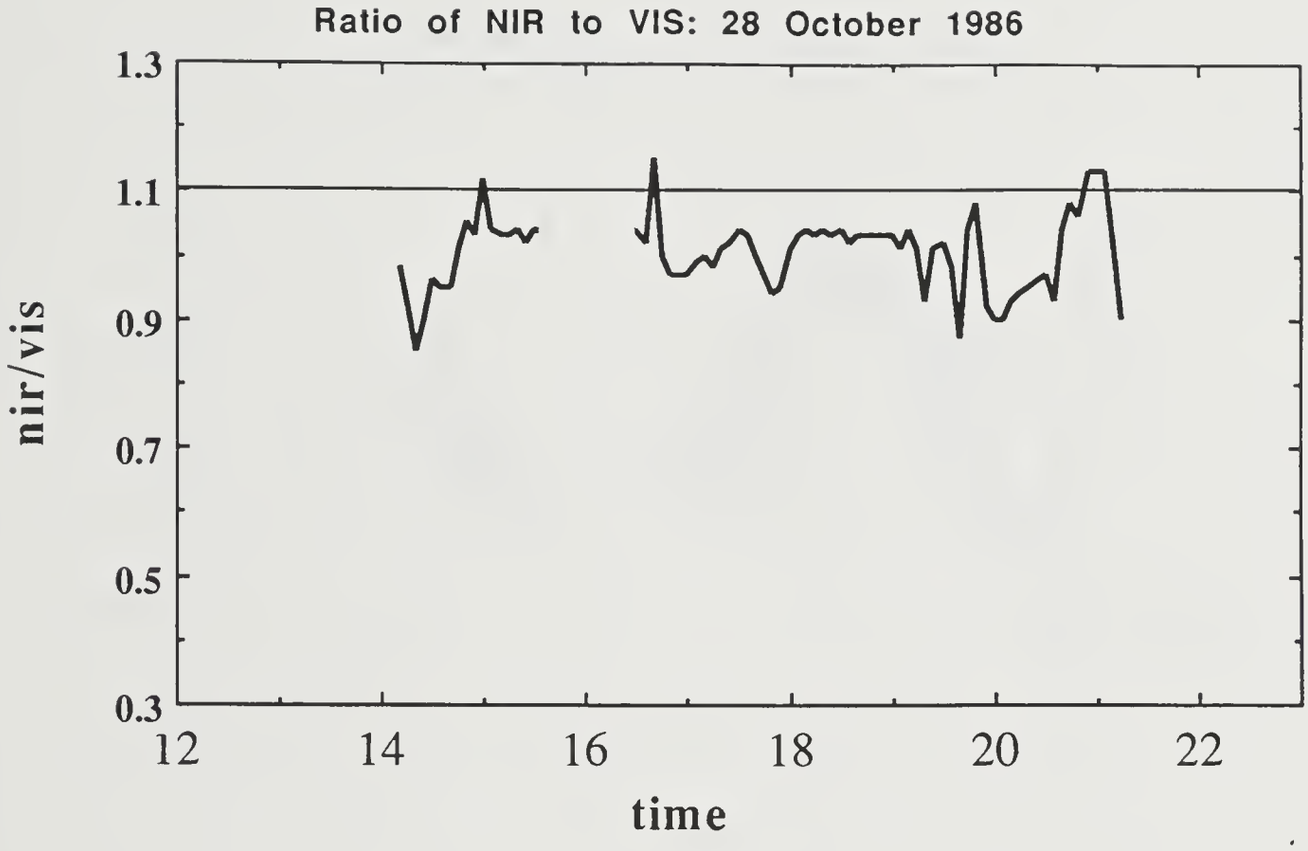

Optical Depth: 27 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep

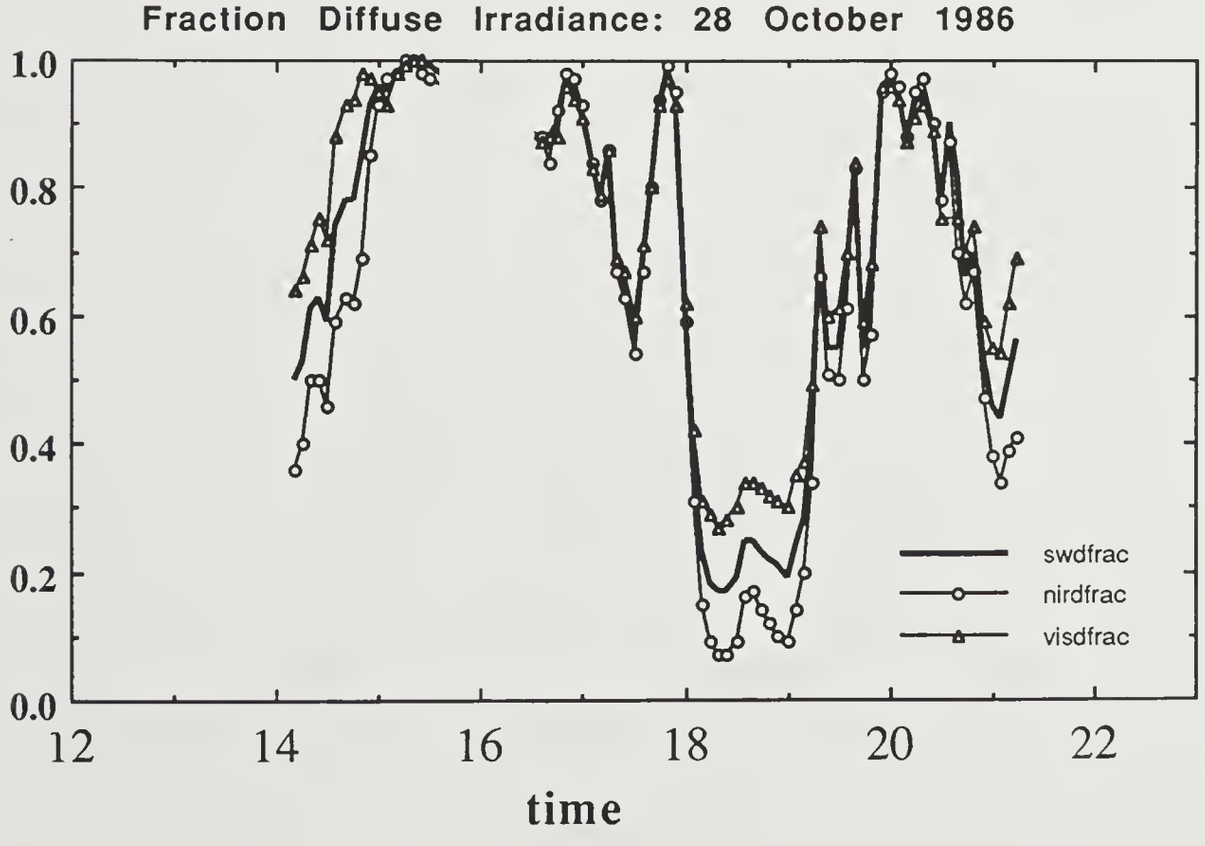

Infrared Irradiance: 27 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn
irup


Net Surface Irradiance: 27 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time


Full Irradiance: 28 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis


Diffuse Irradiance: 28 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd


Ratio of NIR to VIS: 28 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time


Fraction Diffuse Irradiance: 28 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
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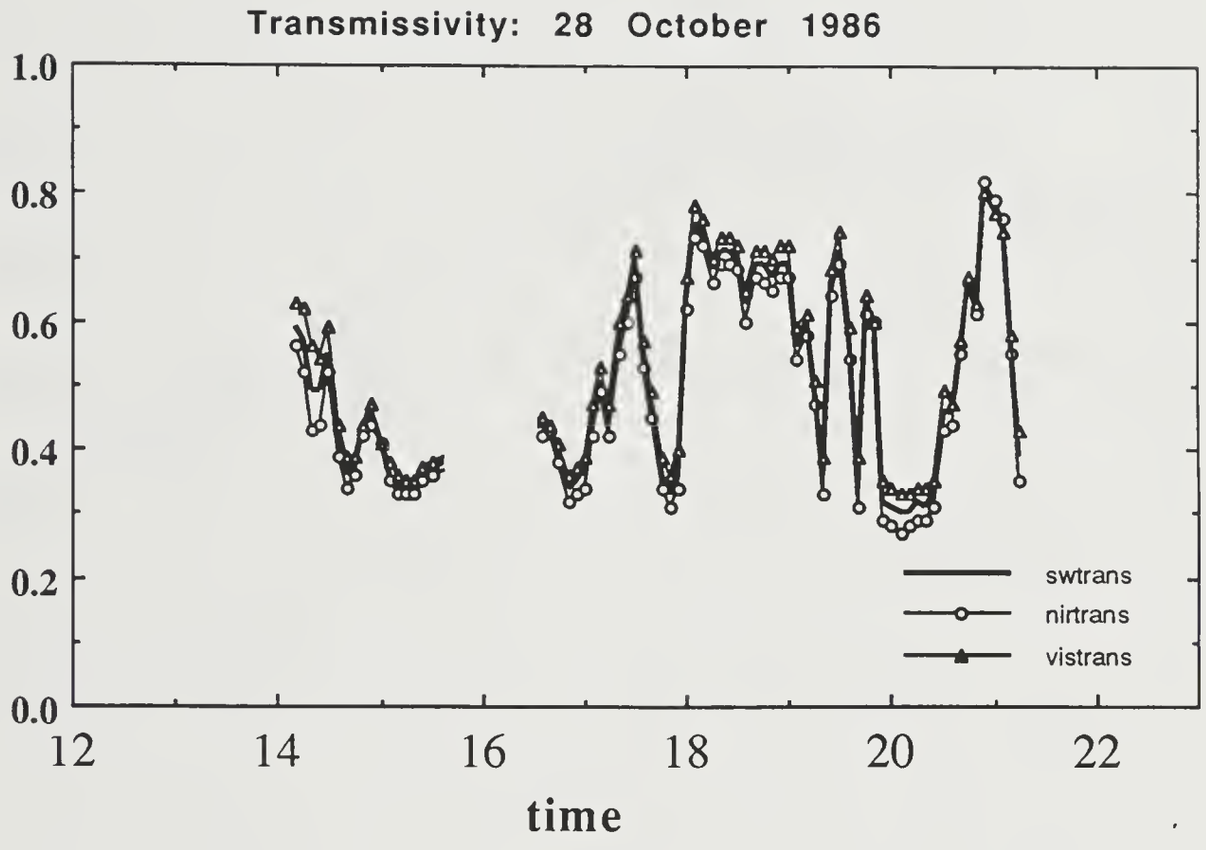
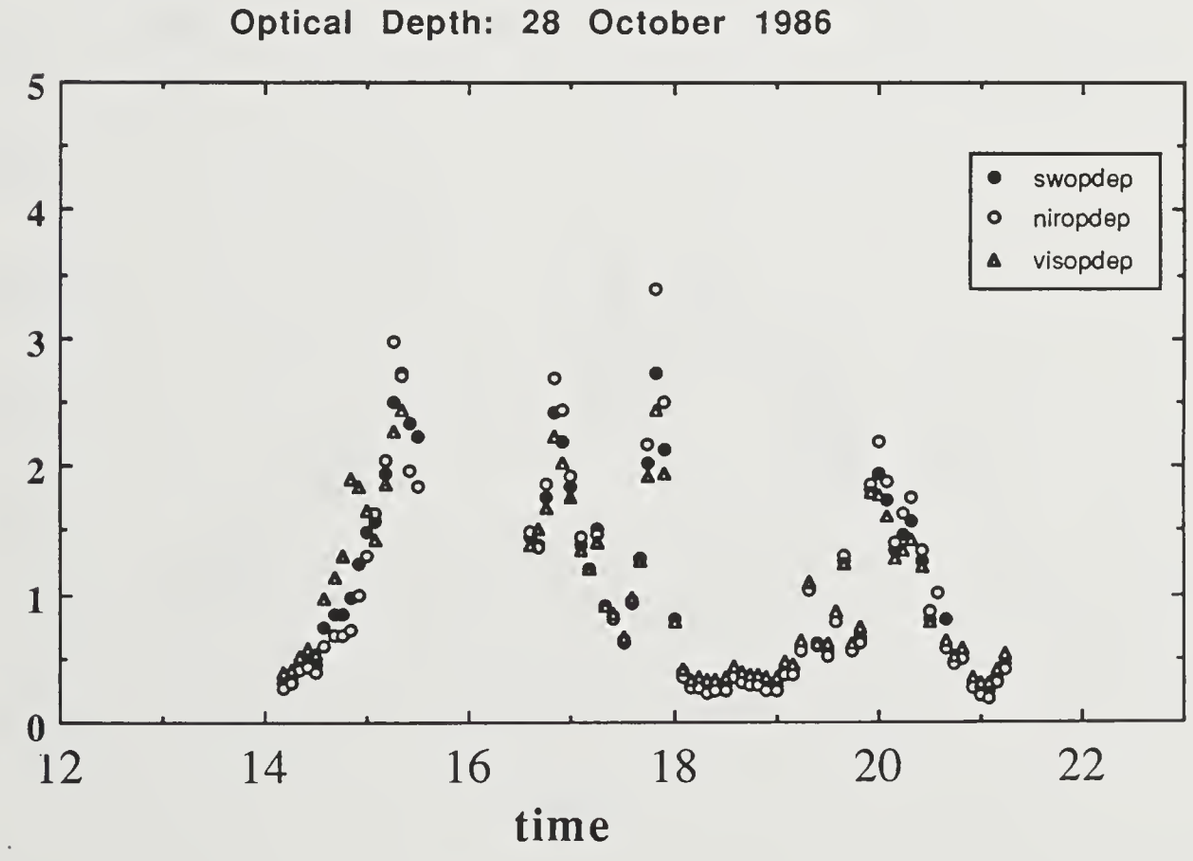
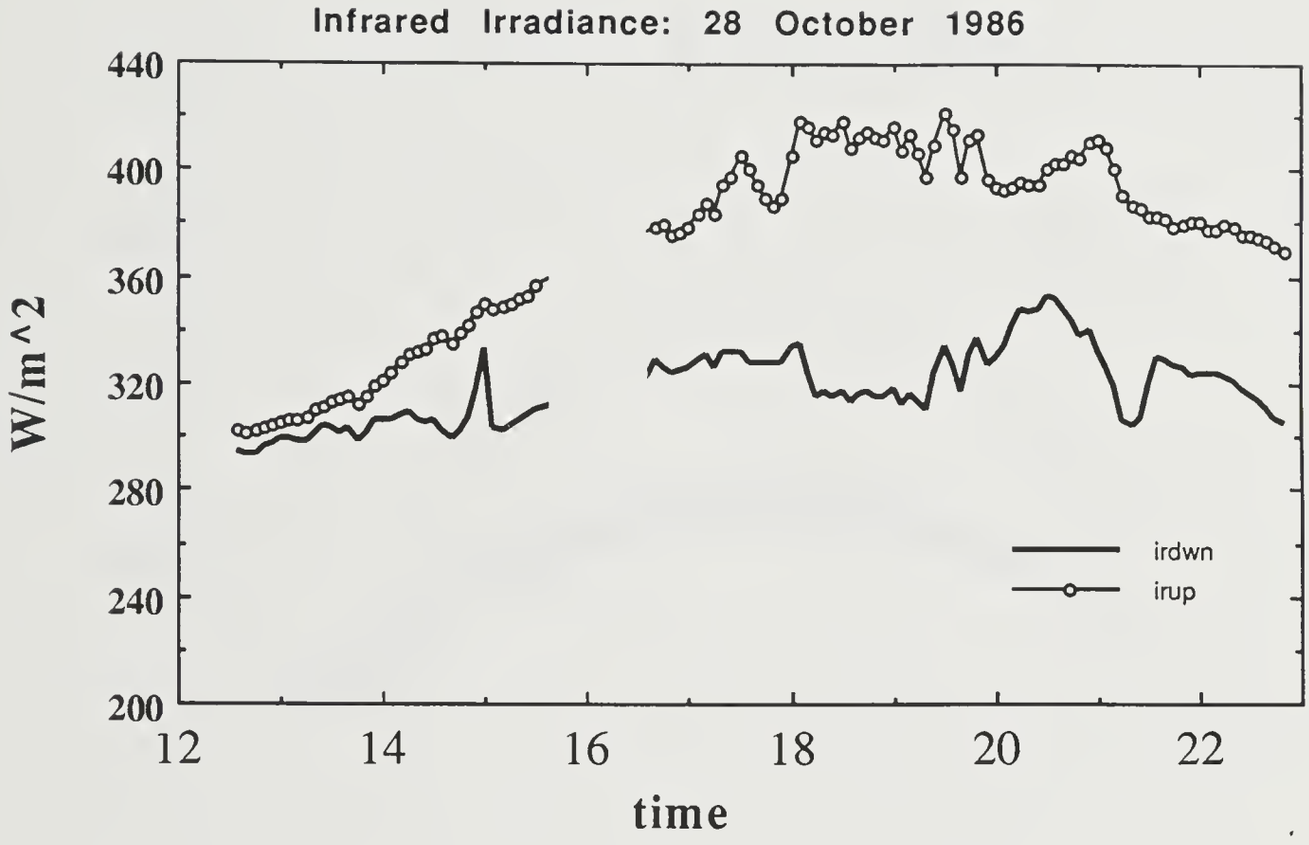
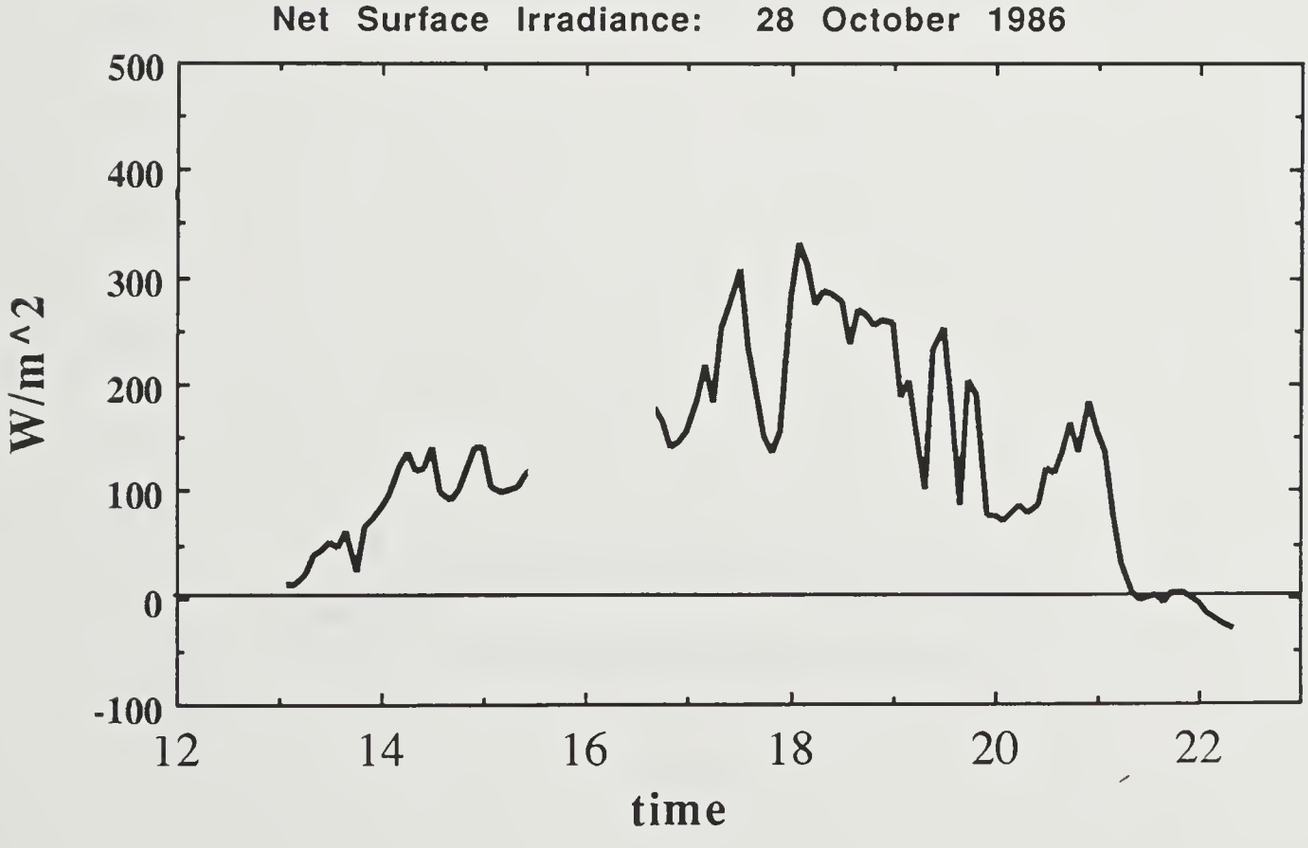
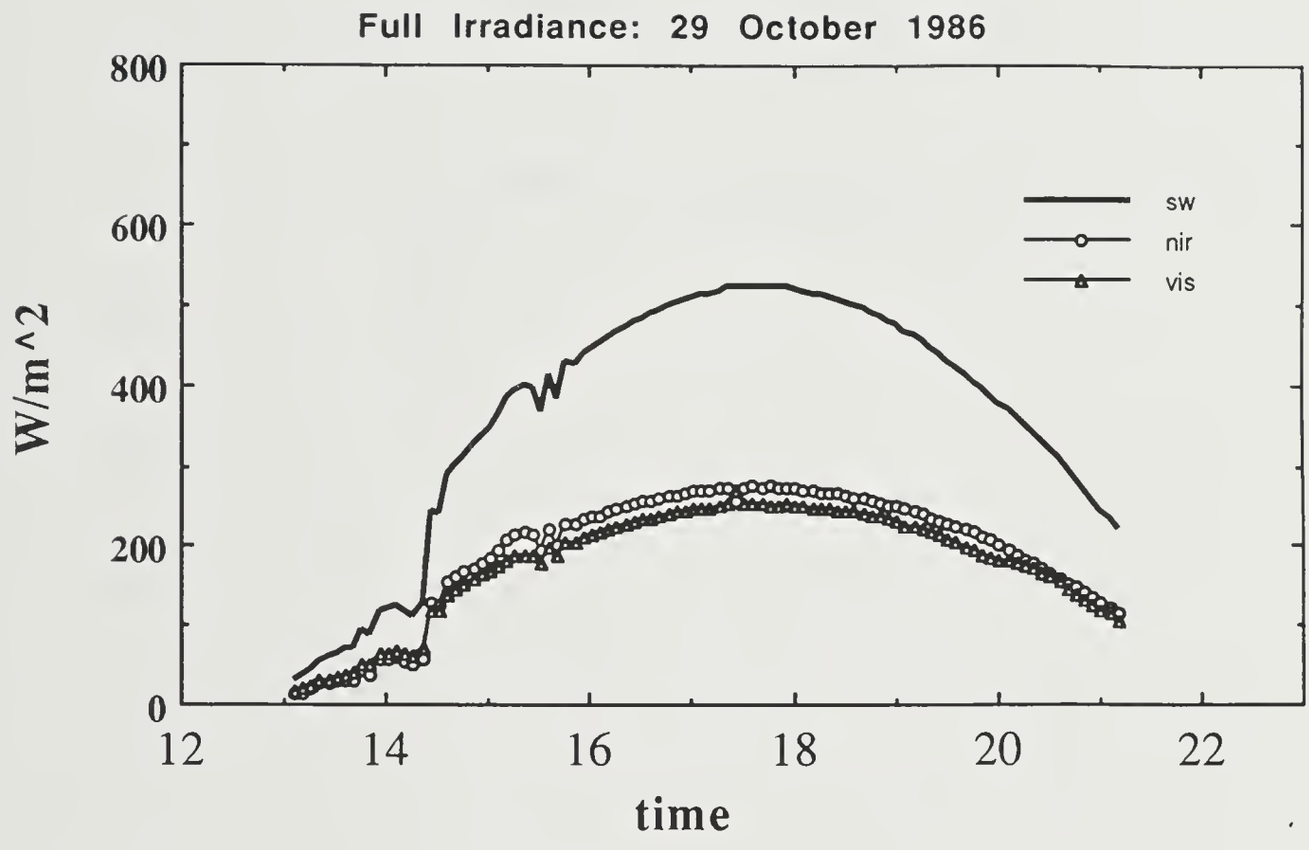
time
swdfrac
nirdfrac
visdfrac

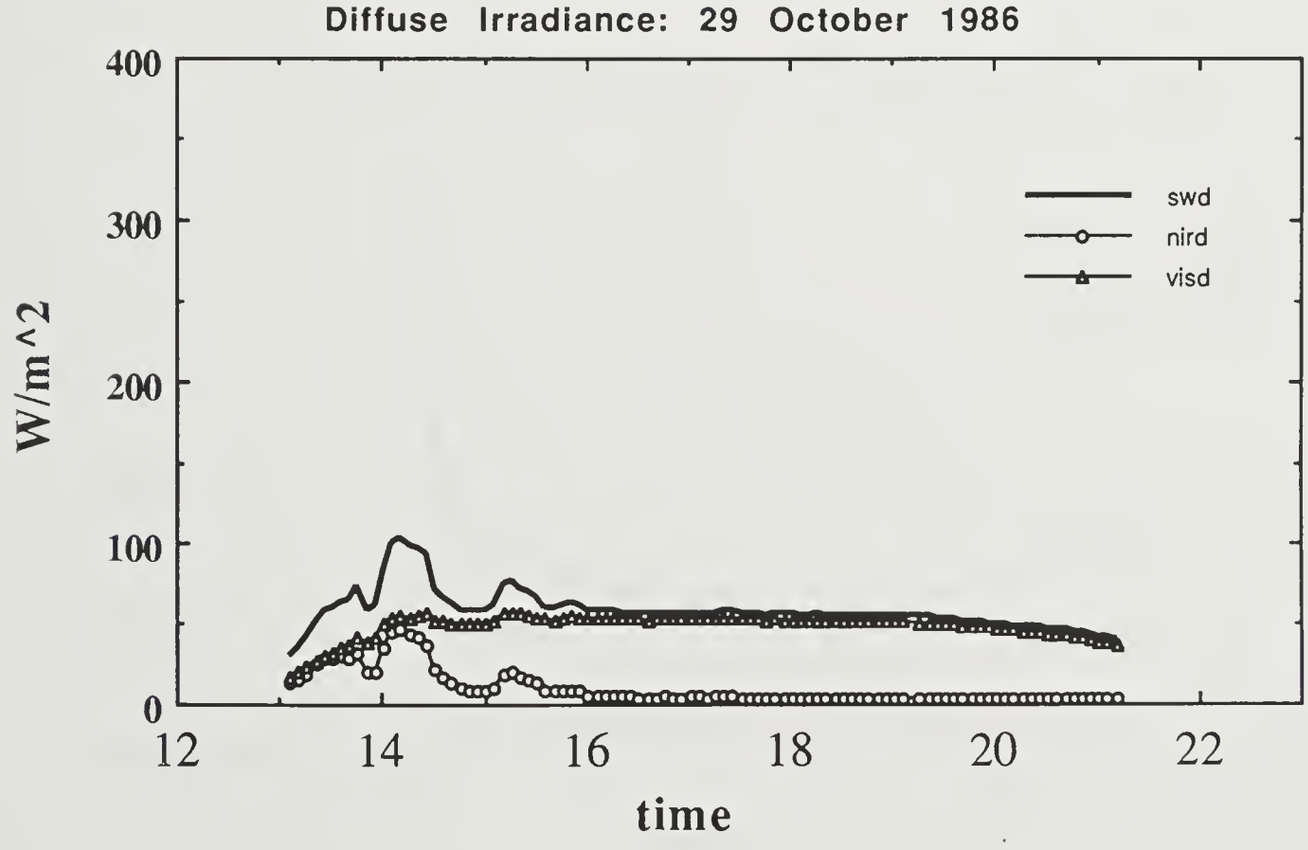

Transmissivity: 28 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

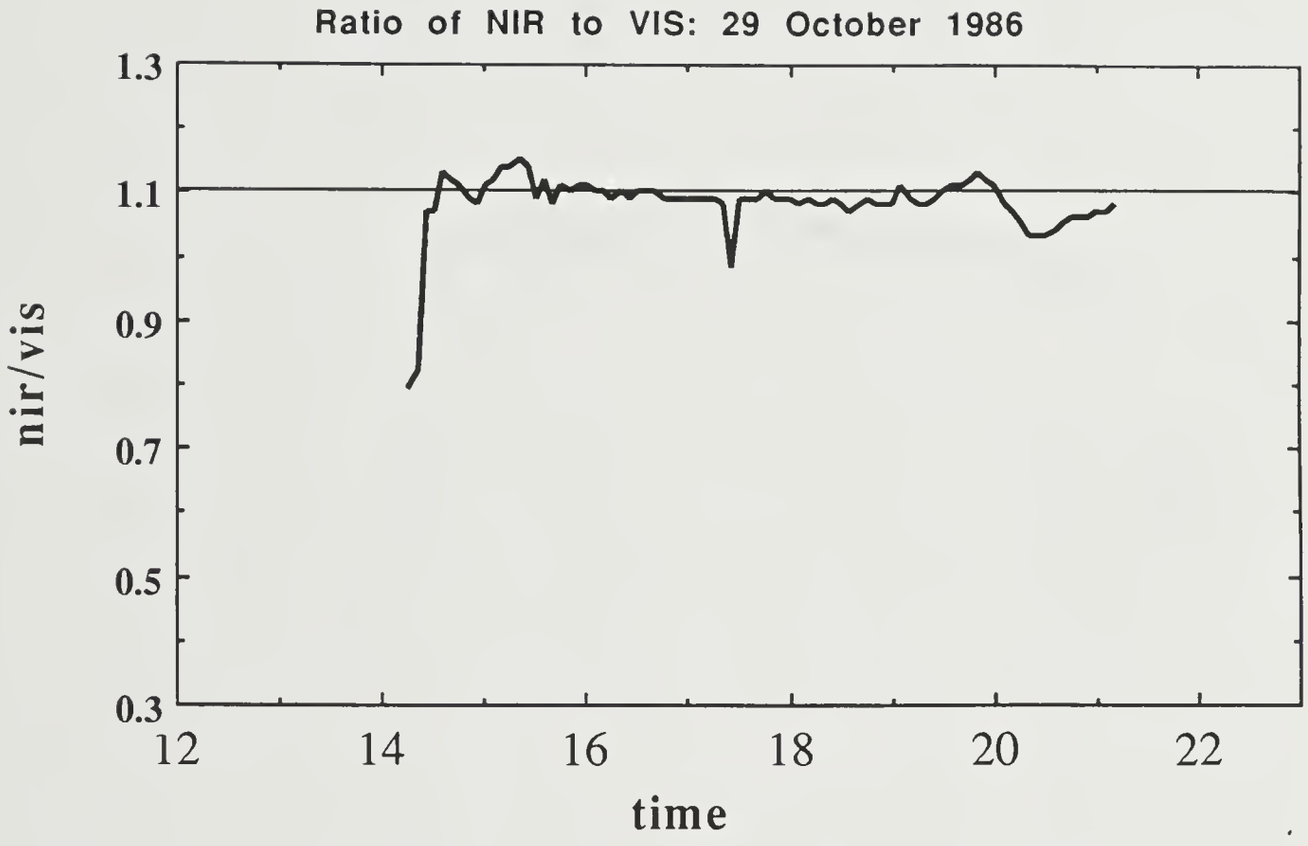

Optical Depth: 28 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep
niropdep
visopdep

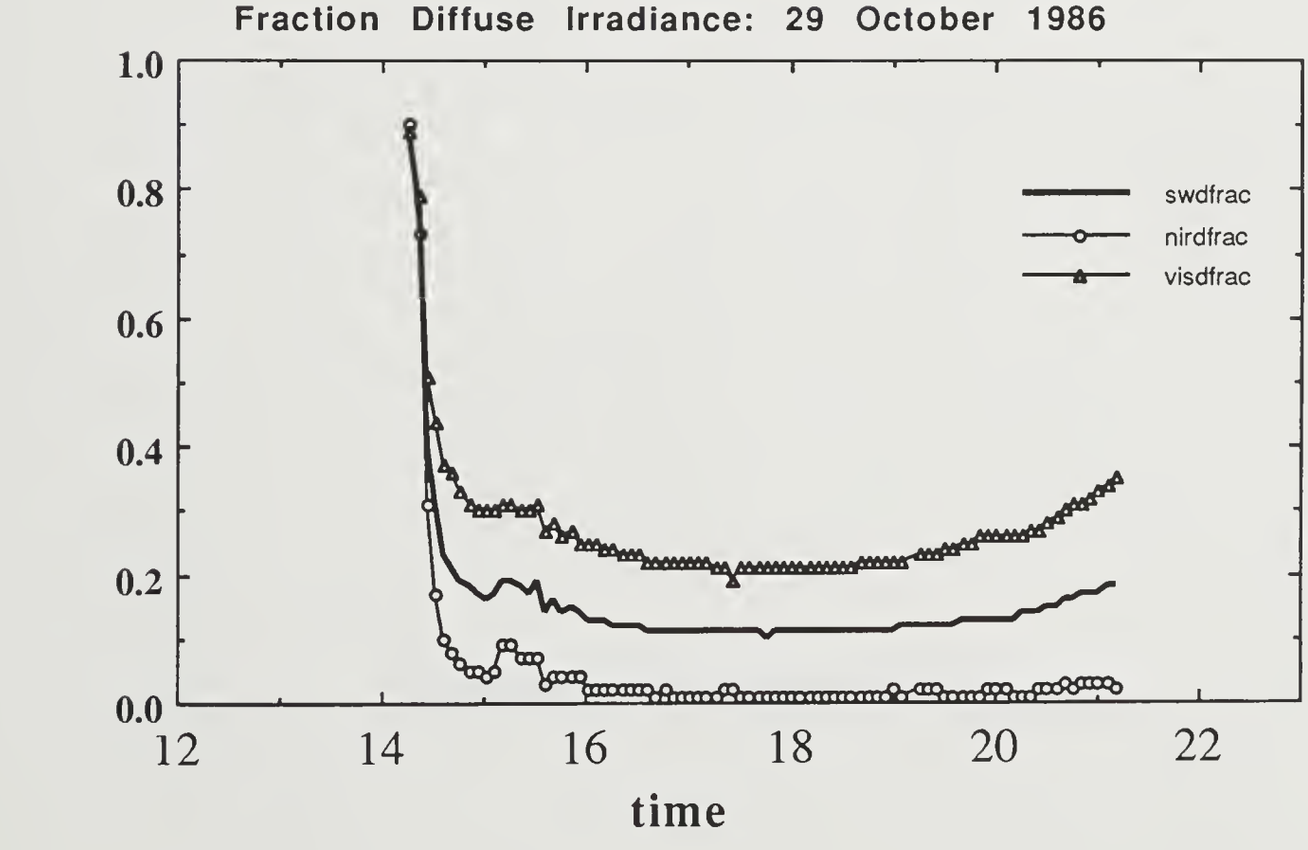

Infrared Irradiance: 28 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn
irup

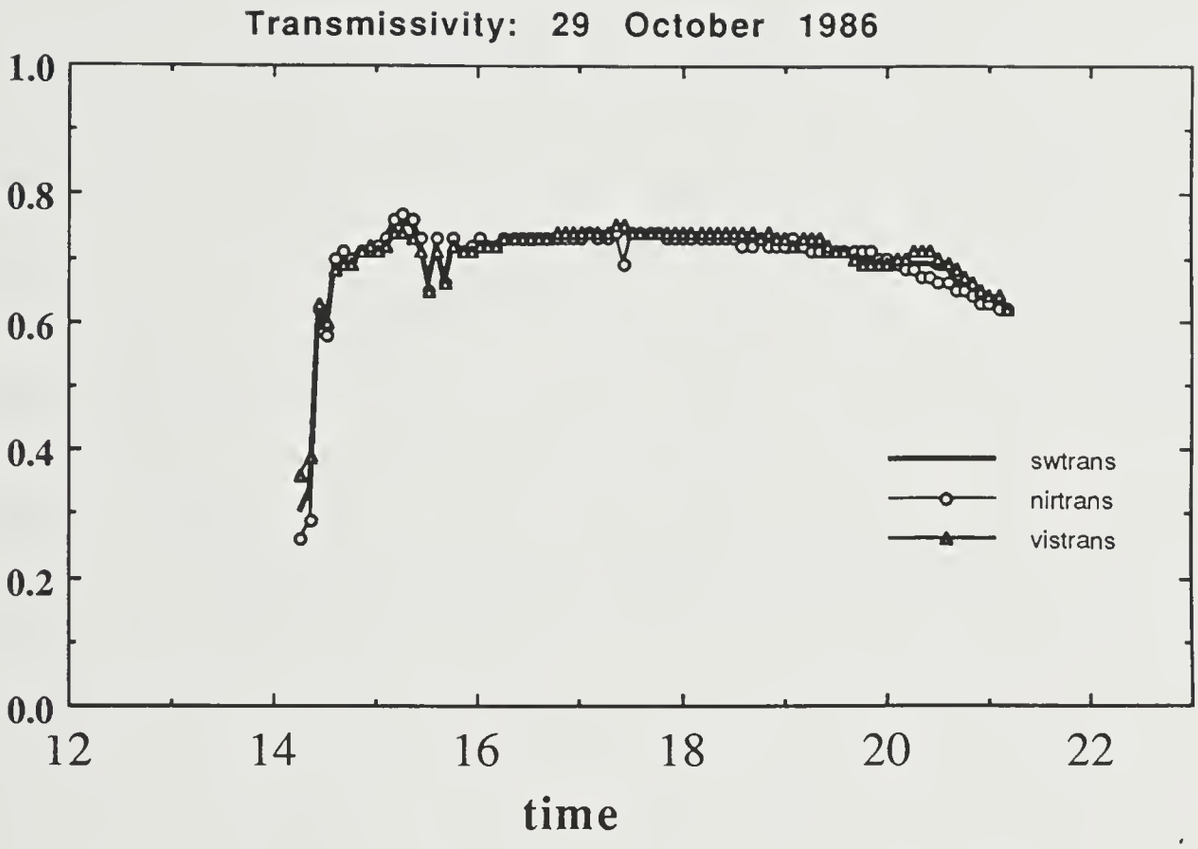

Net Surface Irradiance: 28 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time

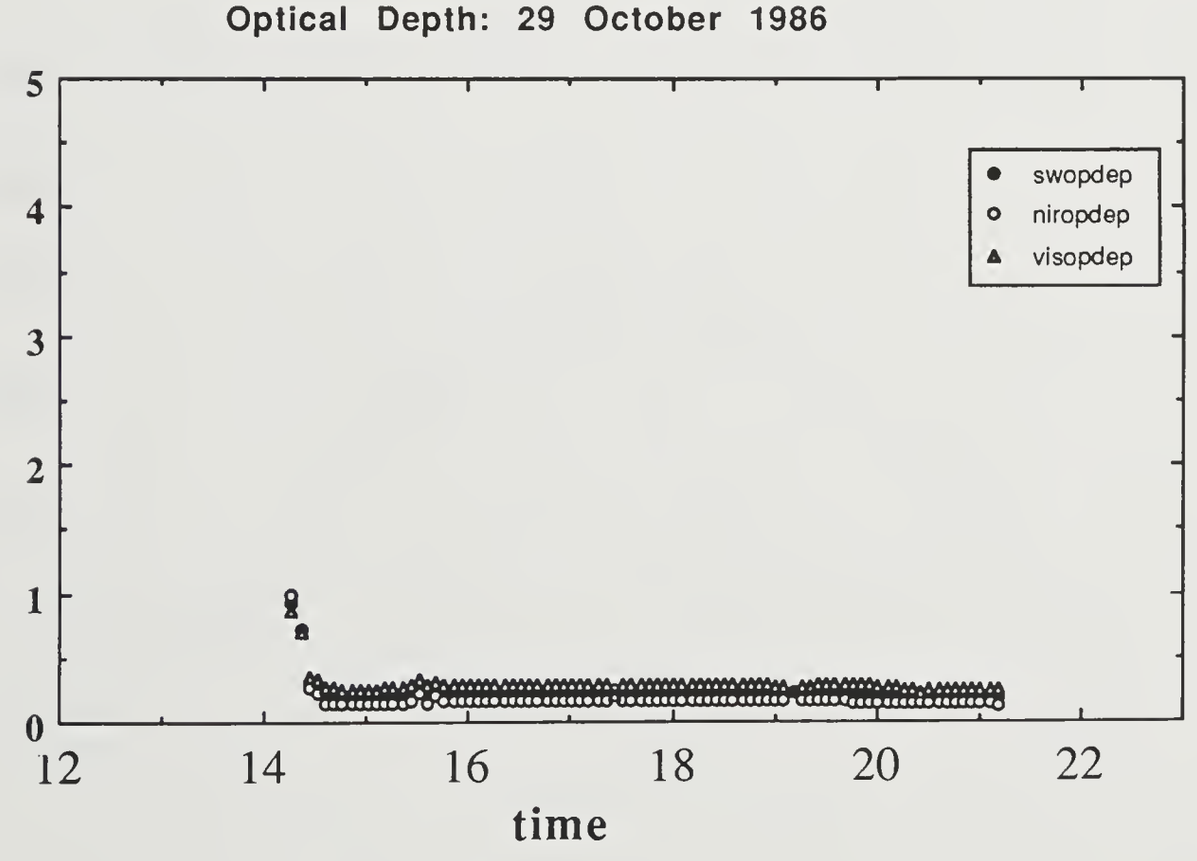

Full Irradiance: 29 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

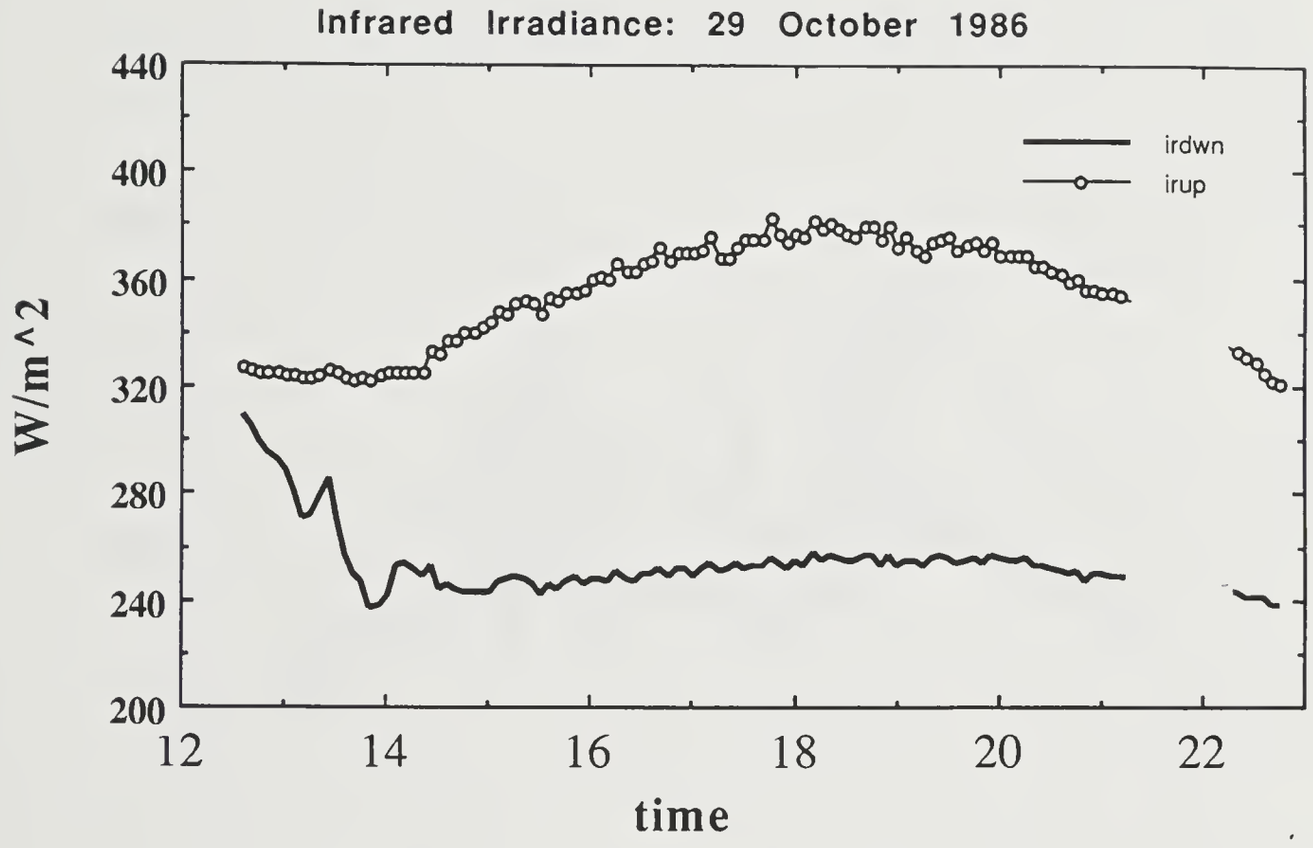

Diffuse Irradiance: 29 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd

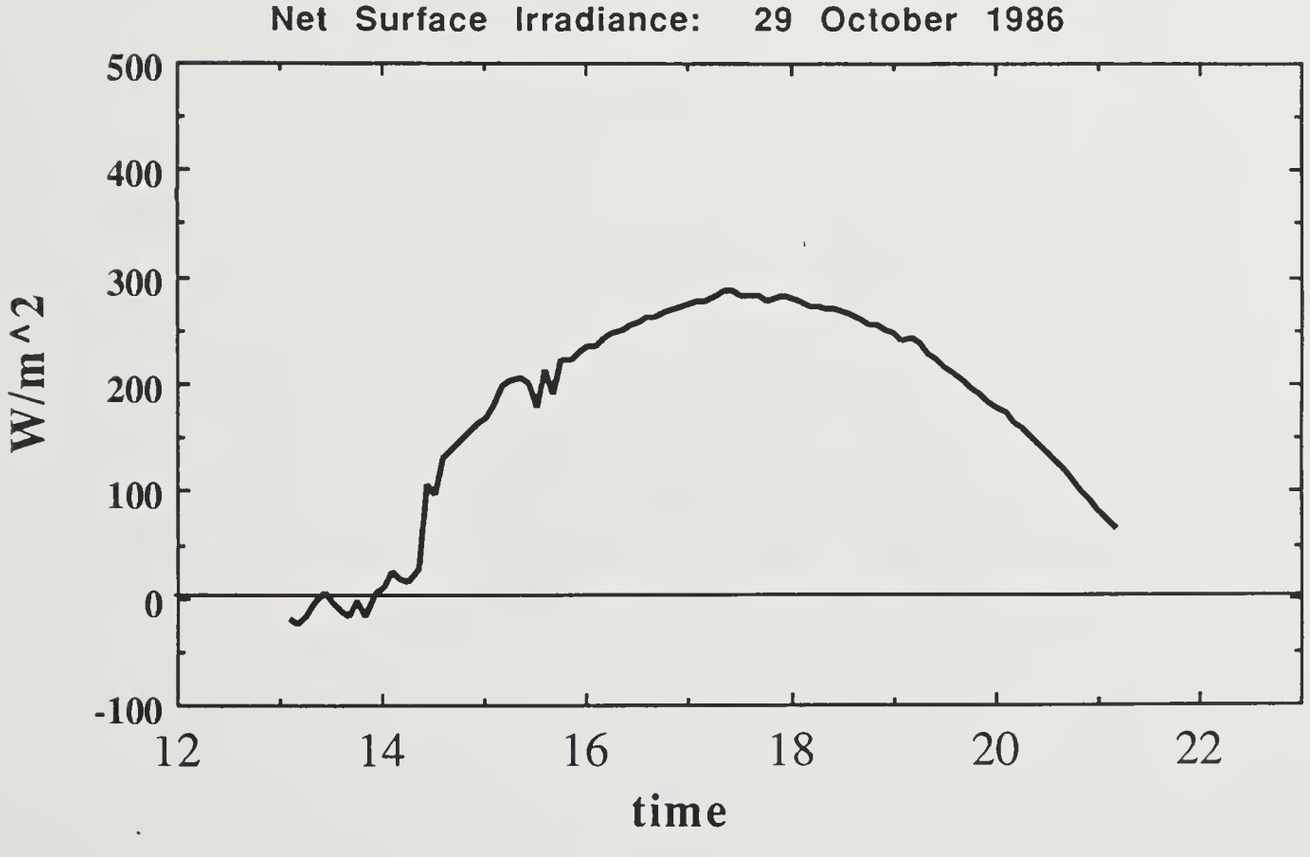

Ratio of NIR to VIS: 29 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time

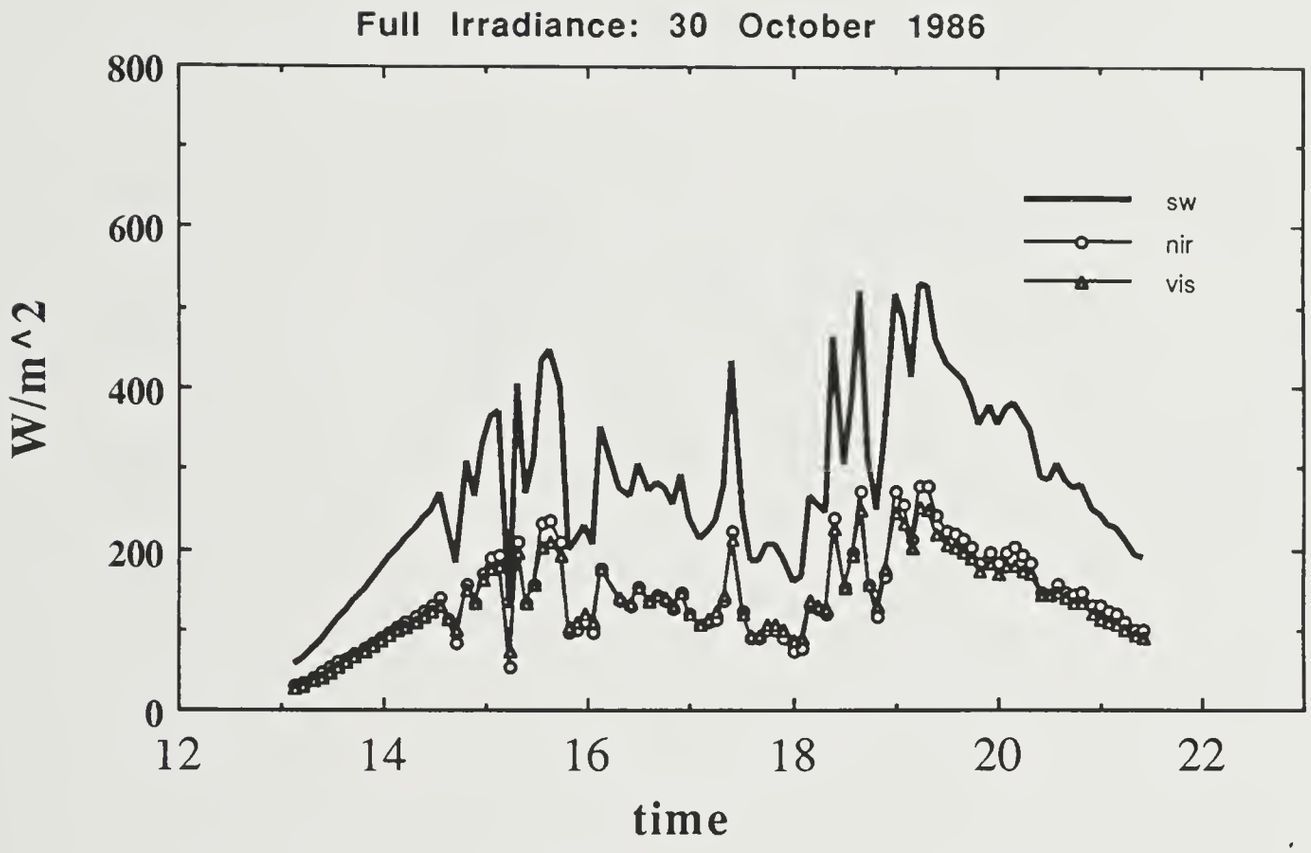

Fraction Diffuse Irradiance: 29 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
swdfrac
nirdfrac
visdfrac
12
14
16
18
20
22
time

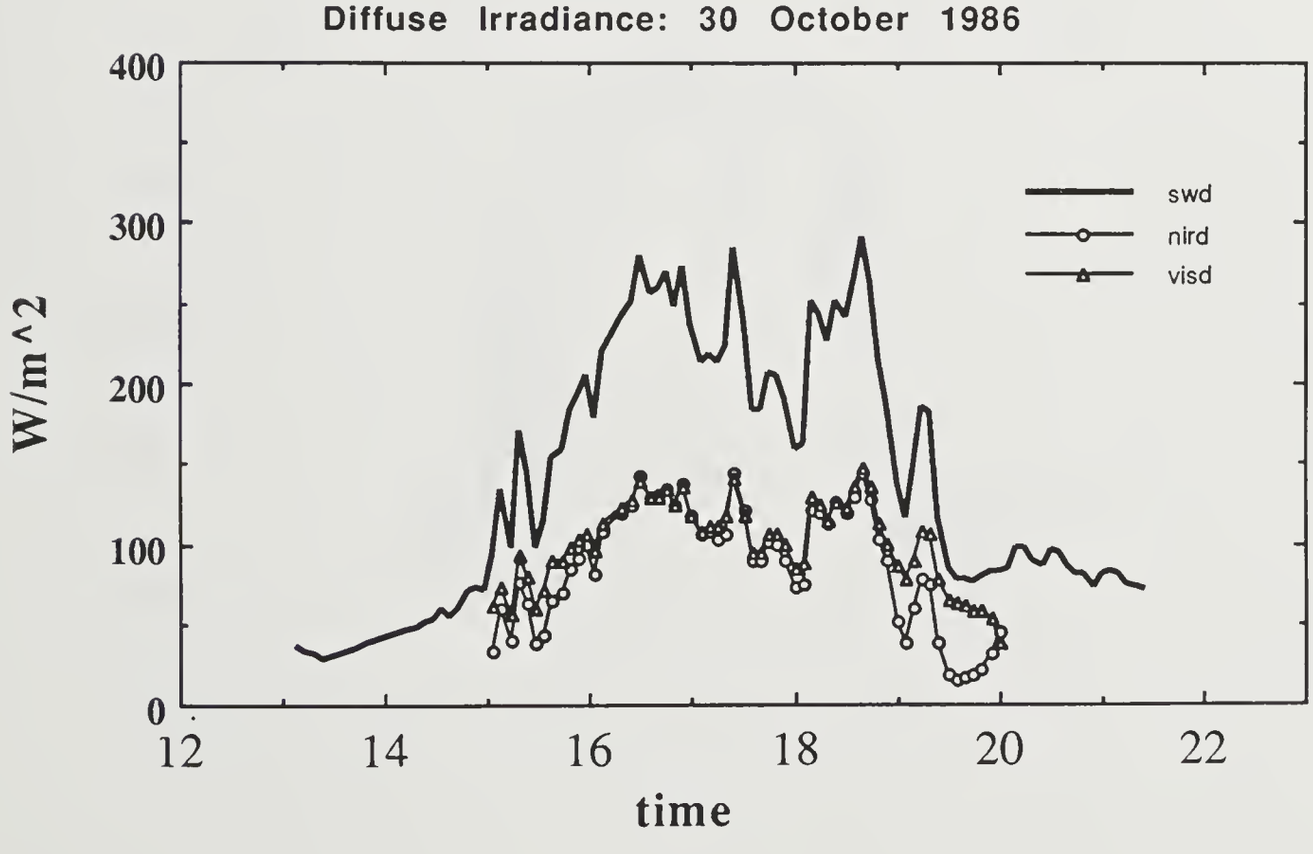

Transmissivity: 29 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

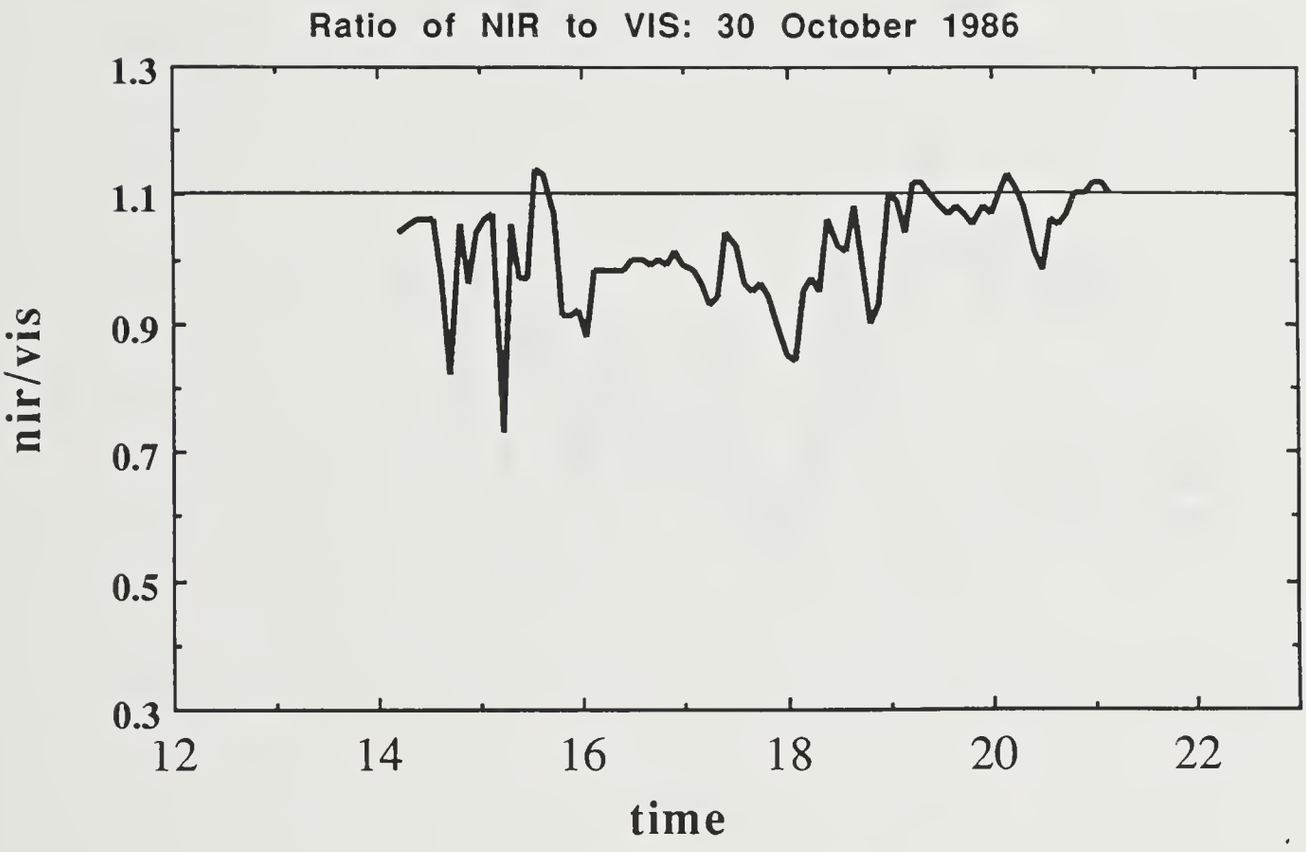

Optical Depth: 29 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep
niropdep
visopdep

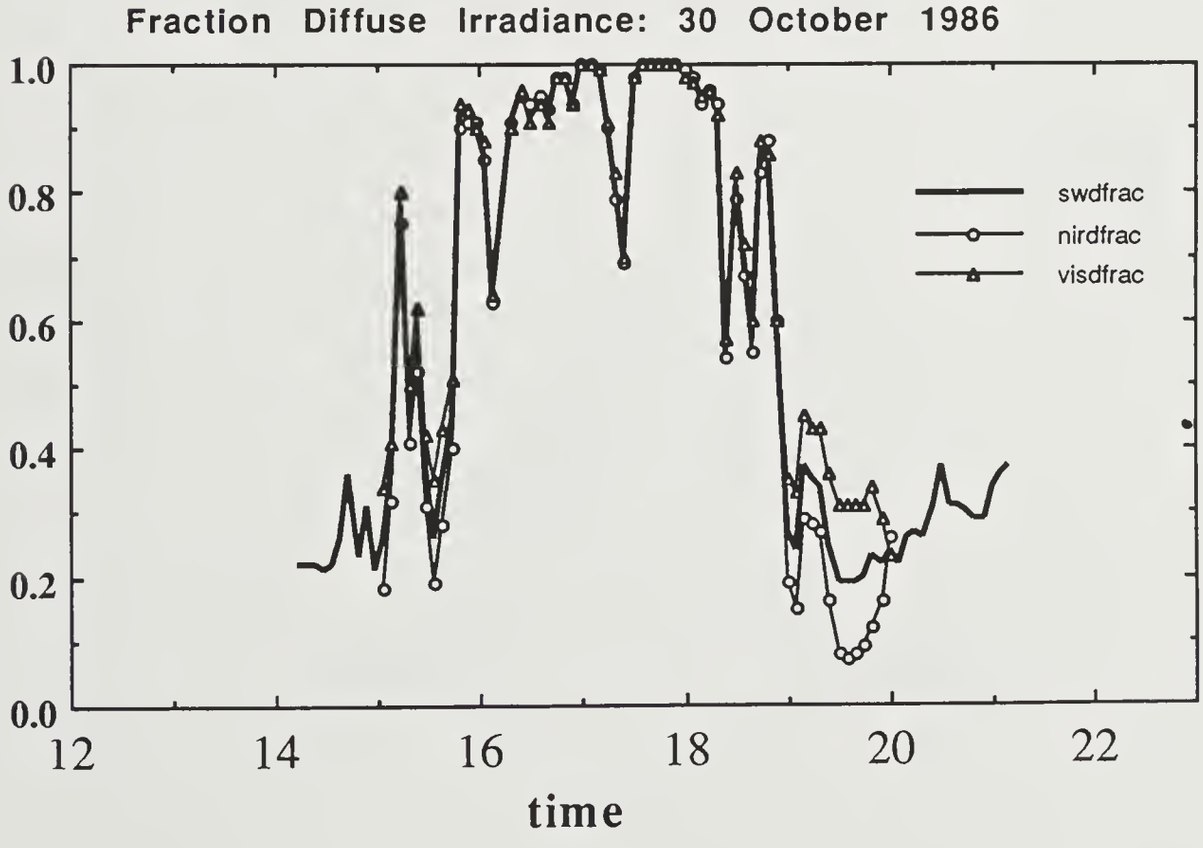

Infrared Irradiance: 29 October 1986
440
400
360
320
280
240
200
W/m^2
irdwn
irup
12
14
16
18
20
22
time

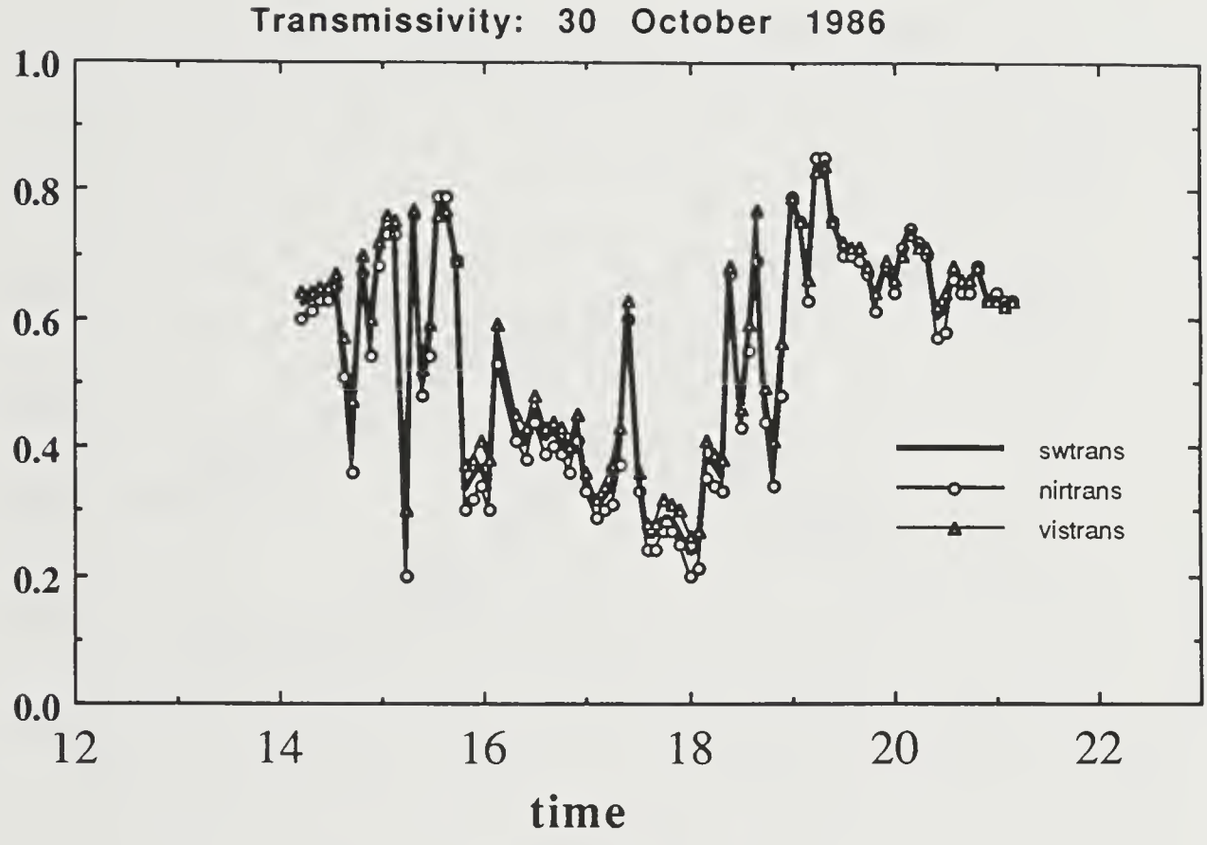

Net Surface Irradiance: 29 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time

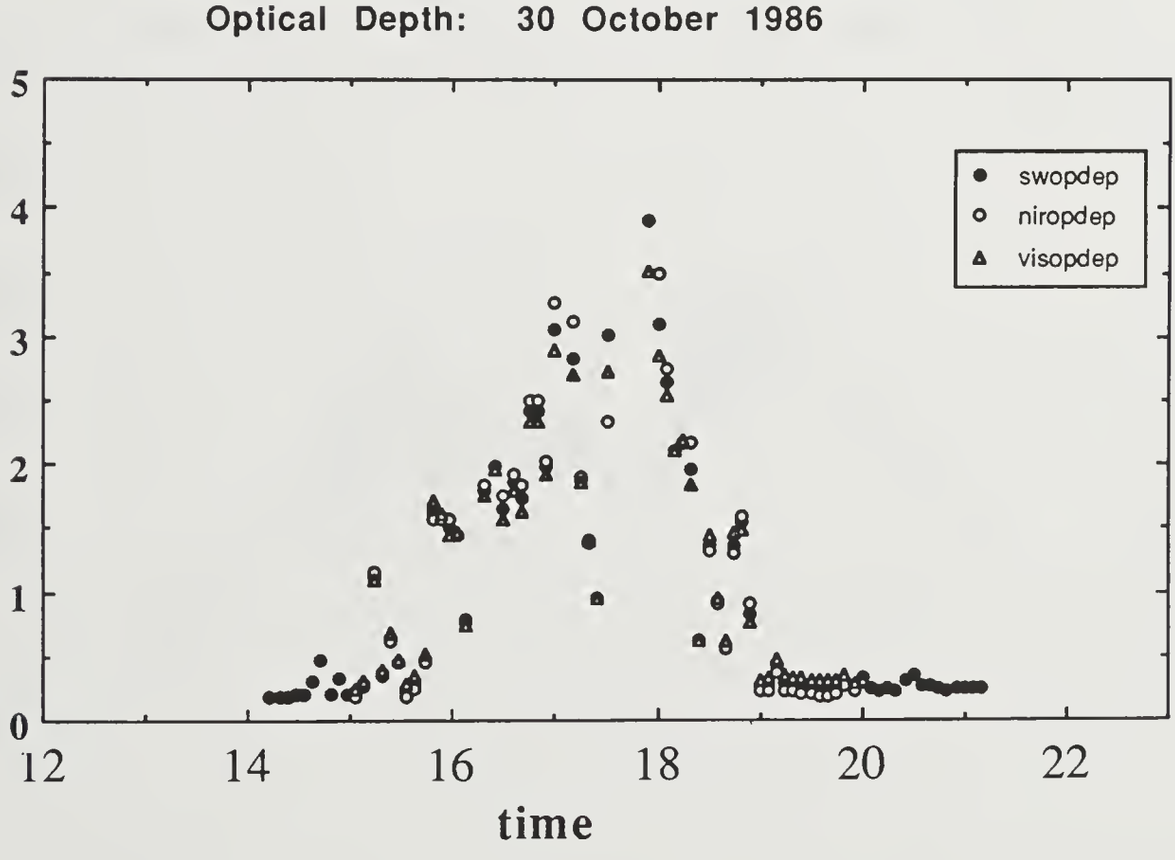

Full Irradiance: 30 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

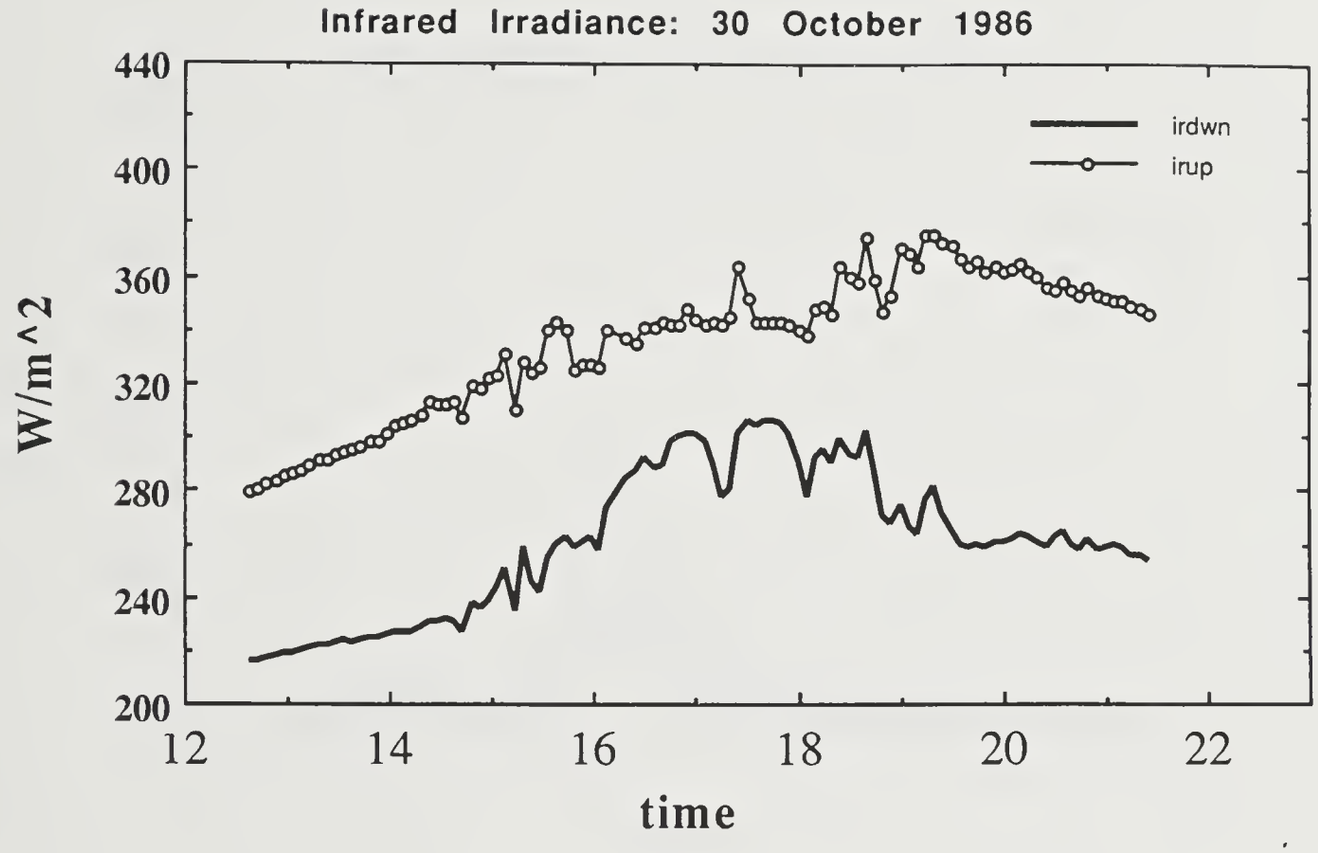

Diffuse Irradiance: 30 October 1986
400
300
200
100
0
W/m^2
12
14
16
18
20
22
time
swd
nird
visd

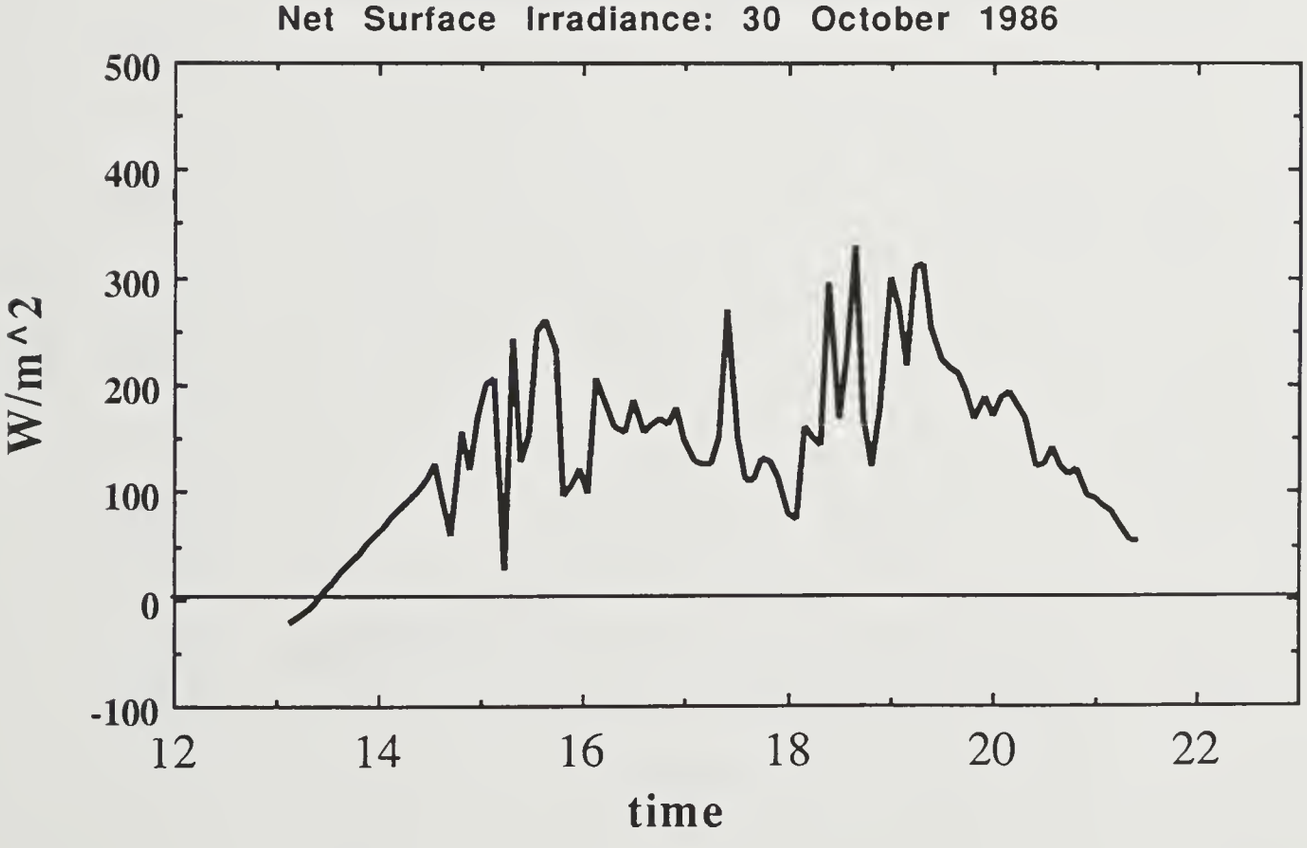

Ratio of NIR to VIS: 30 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time

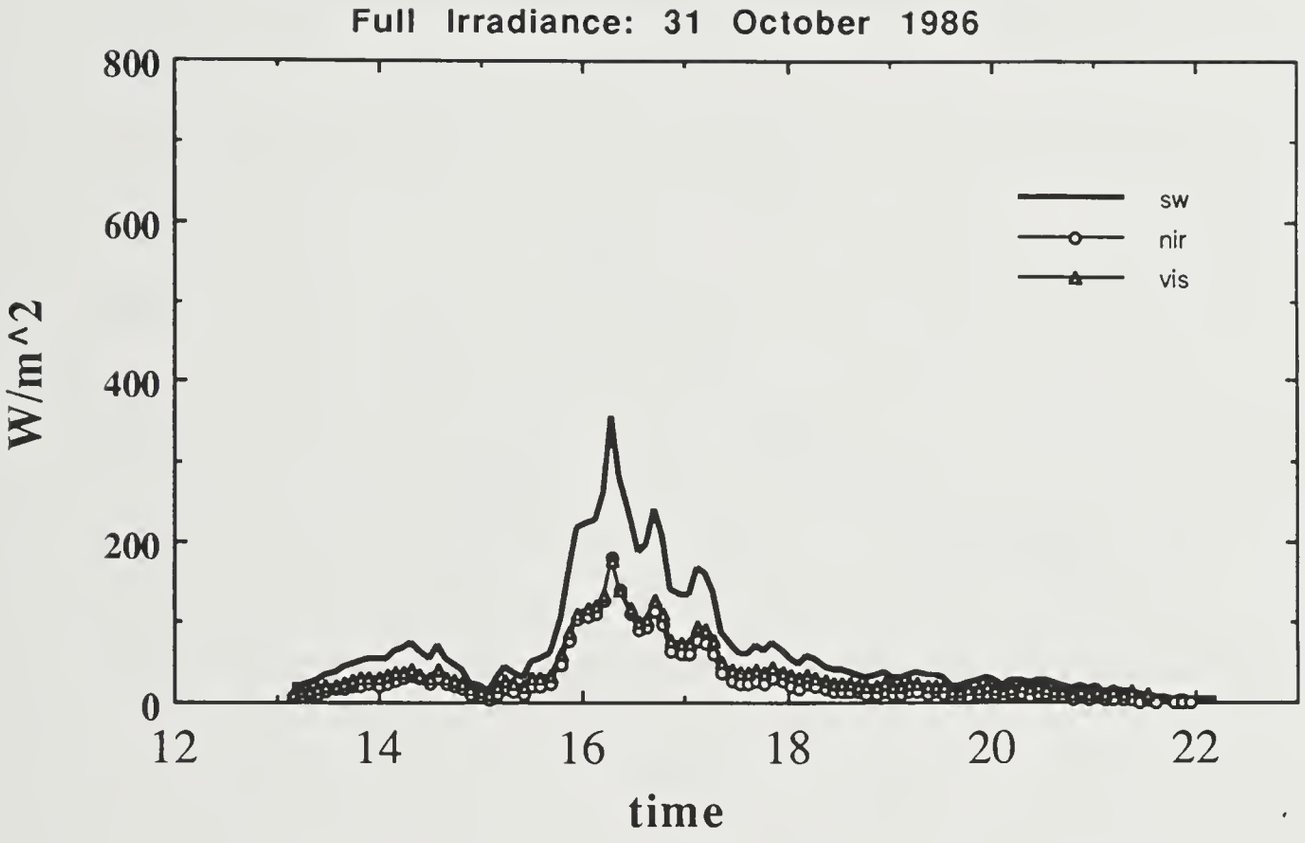

Fraction Diffuse Irradiance: 30 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swdfrac
nirdfrac
visdfrac

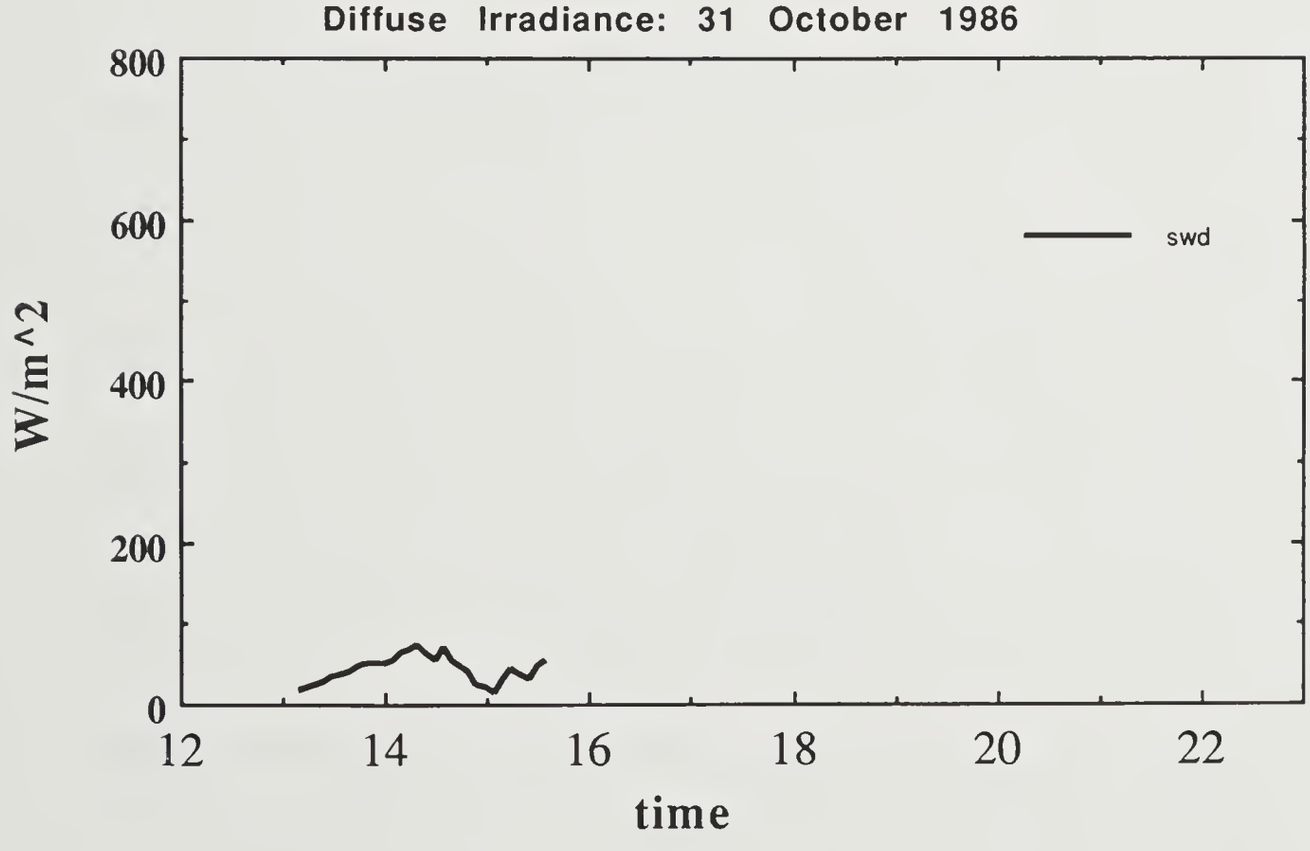

Transmissivity: 30 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

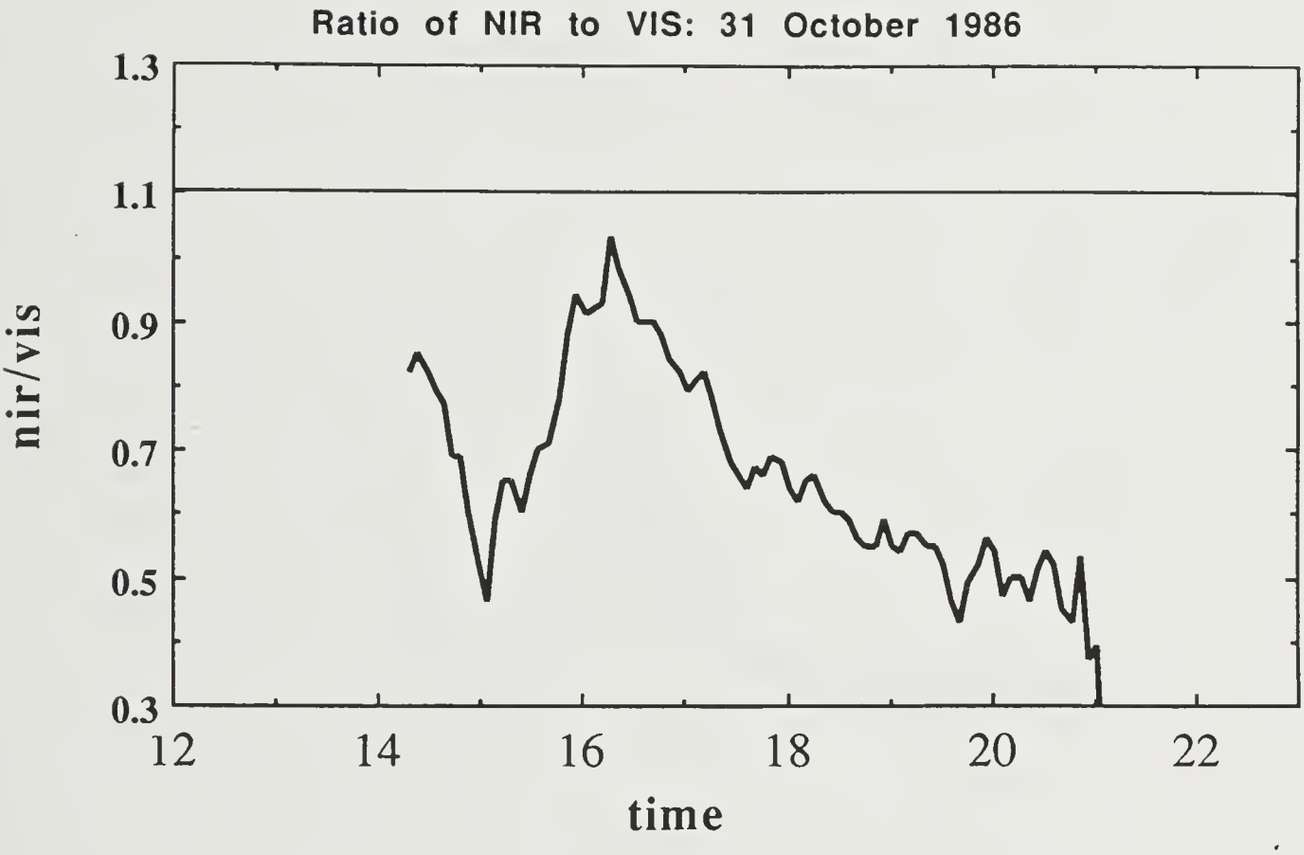

Optical Depth: 30 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep
niropdep
visopdep

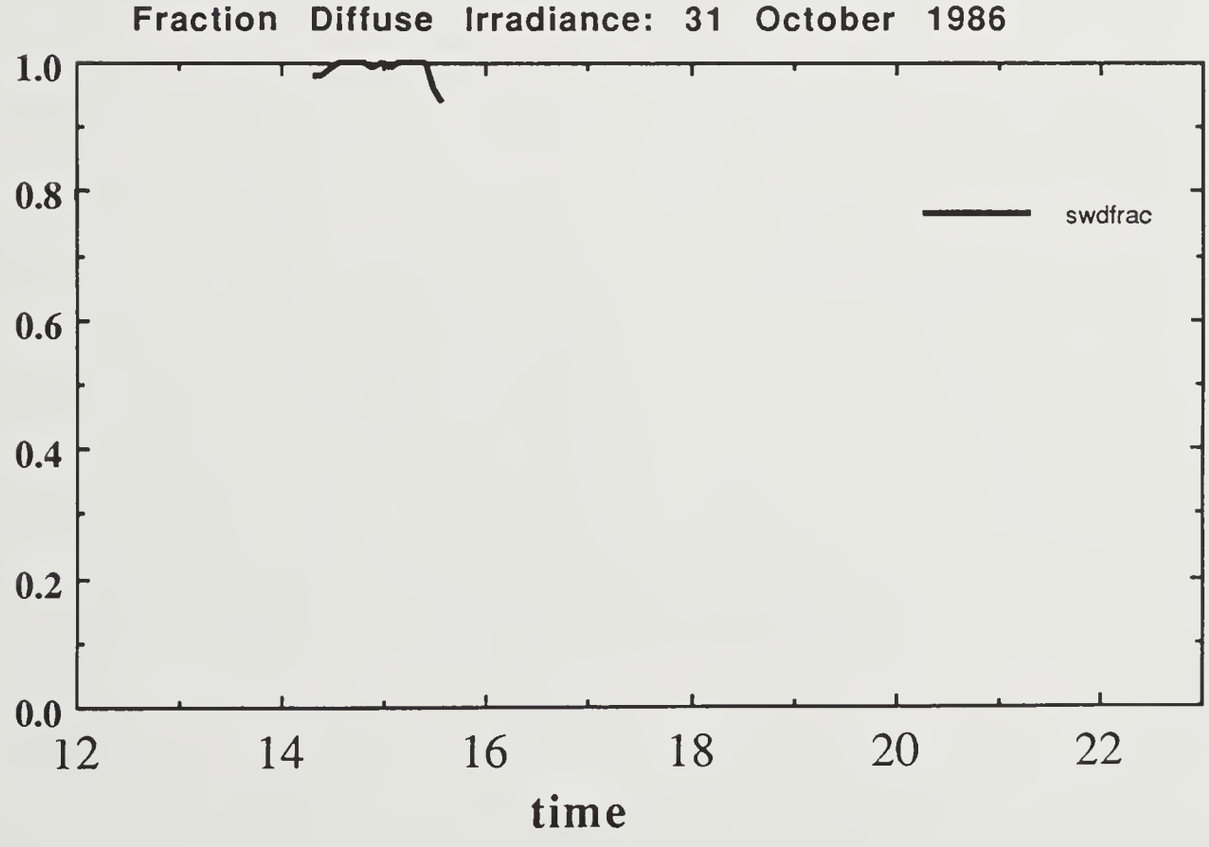

Infrared Irradiance: 30 October 1986
440
400
360
320
280
240
200
W/m^2
12
14
16
18
20
22
time
irdwn
irup

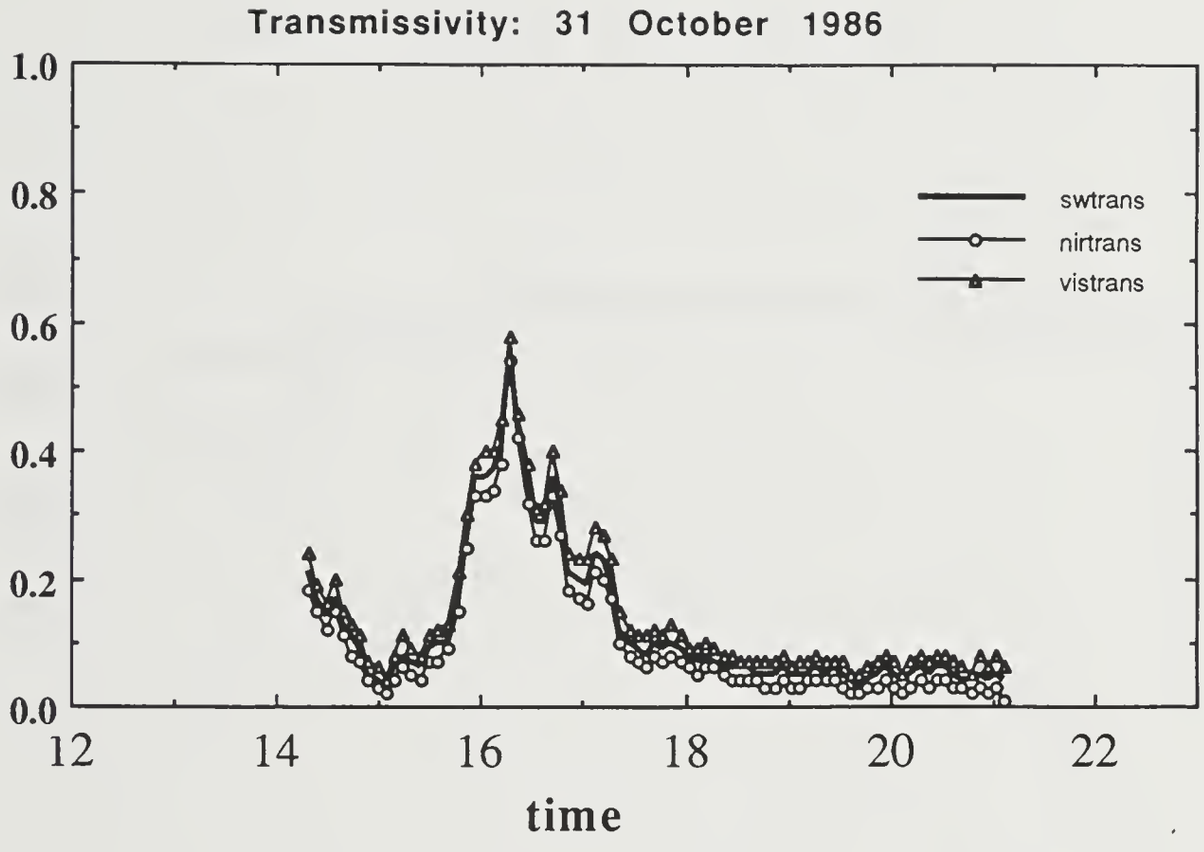

Net Surface Irradiance: 30 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time

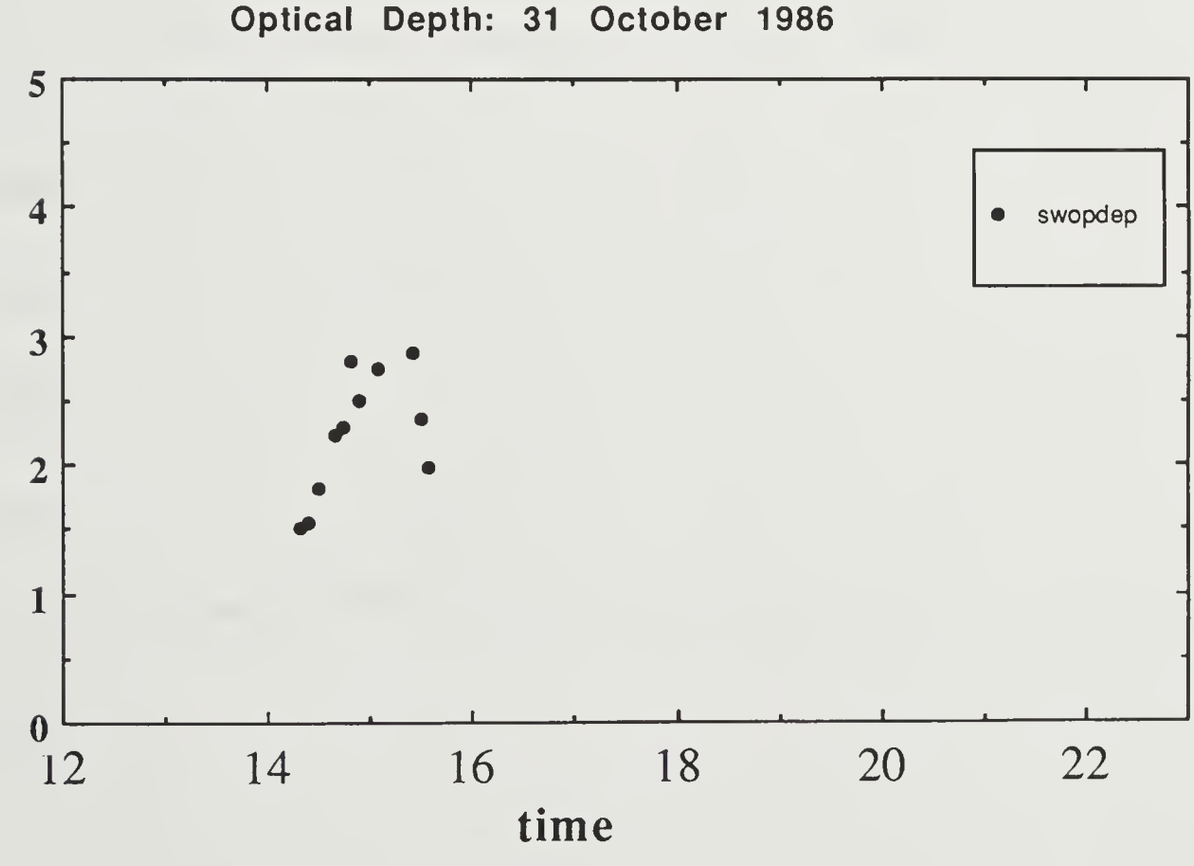

Full Irradiance: 31 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

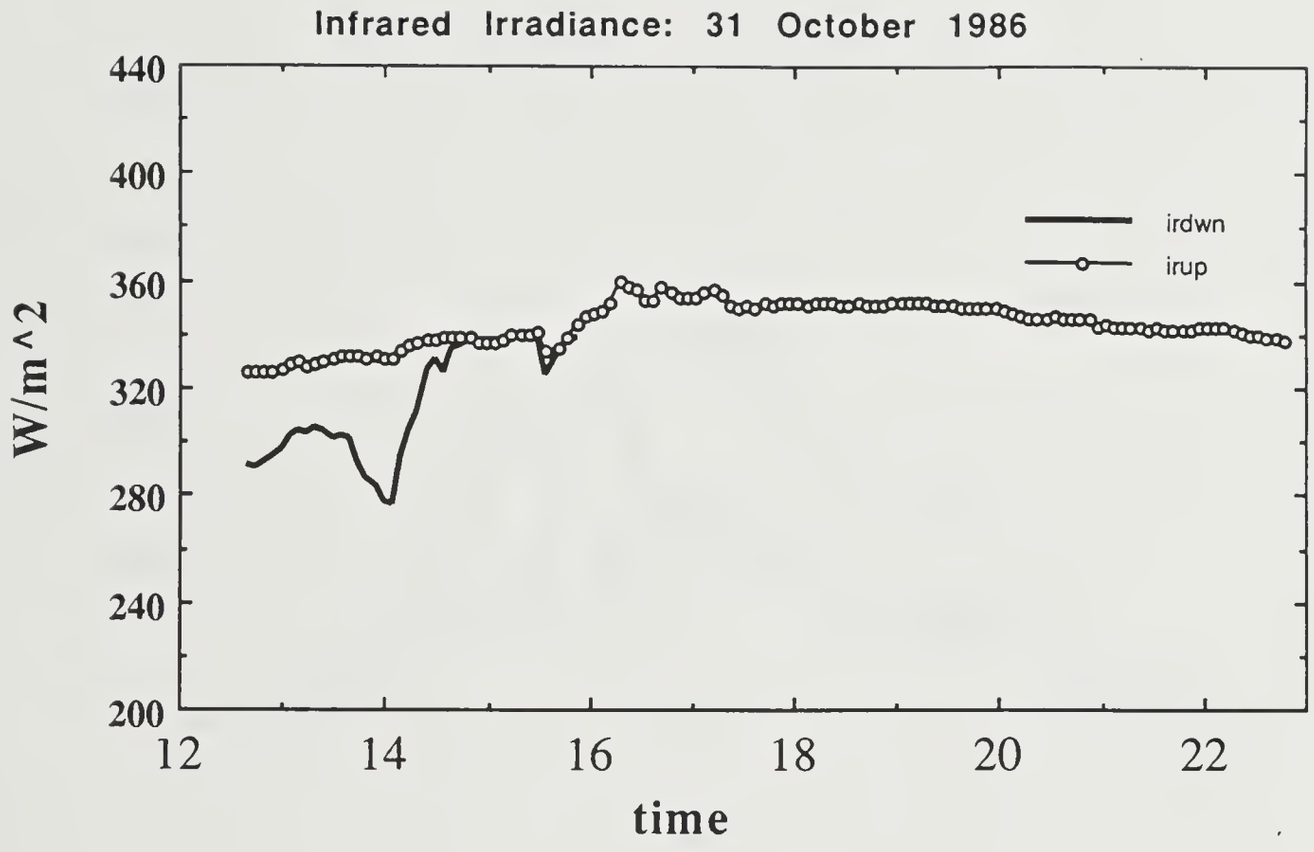

Diffuse Irradiance: 31 October 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
swd

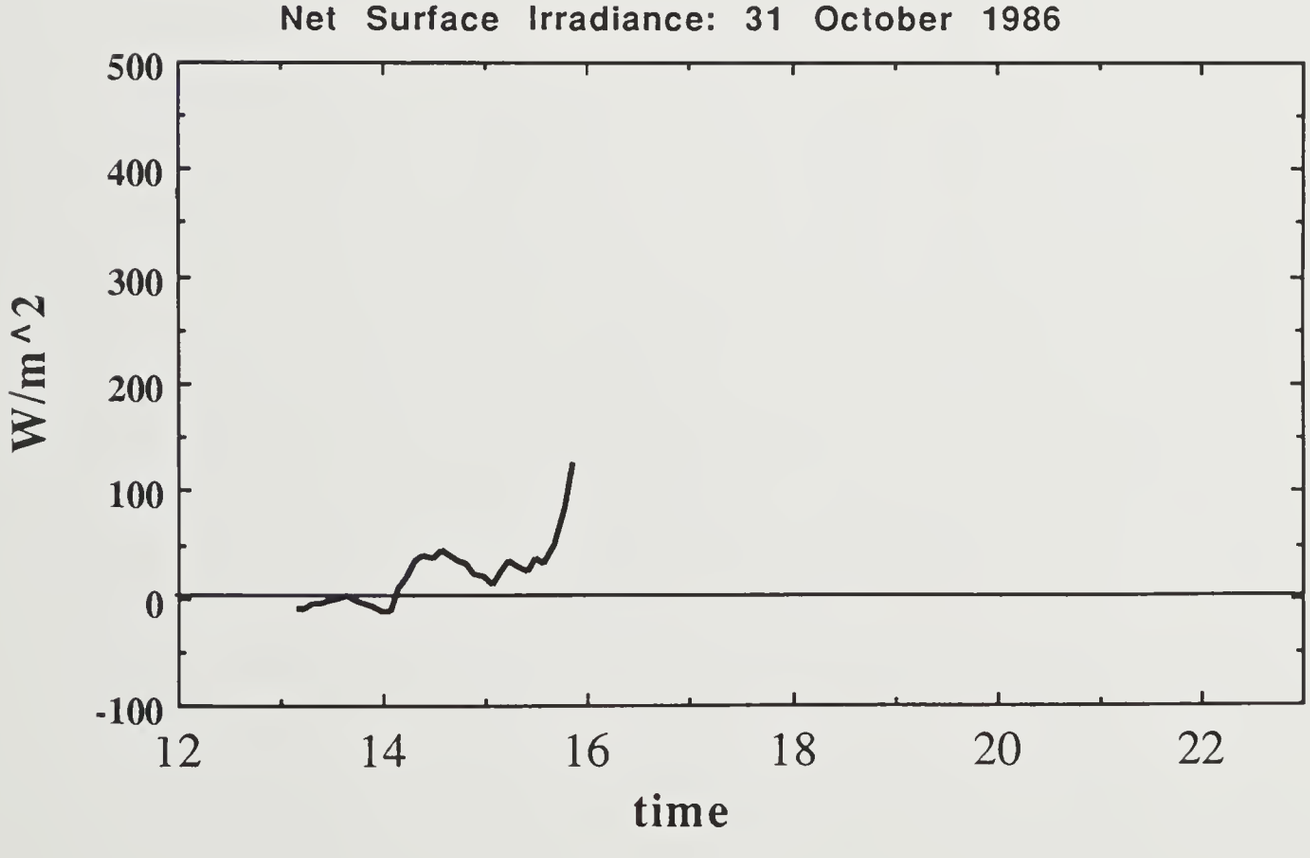

Ratio of NIR to VIS: 31 October 1986
nir/vis
1.3
1.1
0.9
0.7
0.5
0.3
12
14
16
18
20
22
time

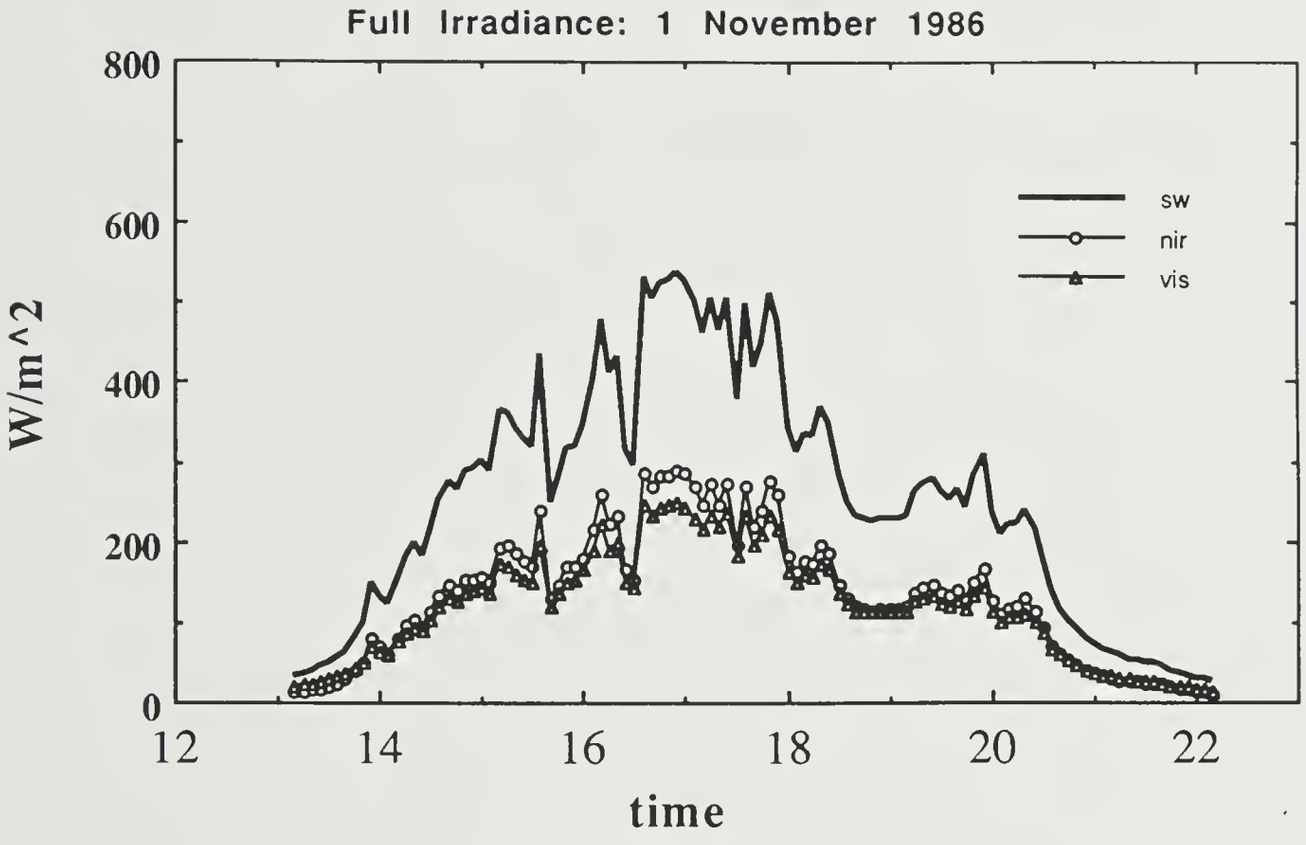

Fraction Diffuse Irradiance: 31 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
swdfrac
12
14
16
18
20
22
time

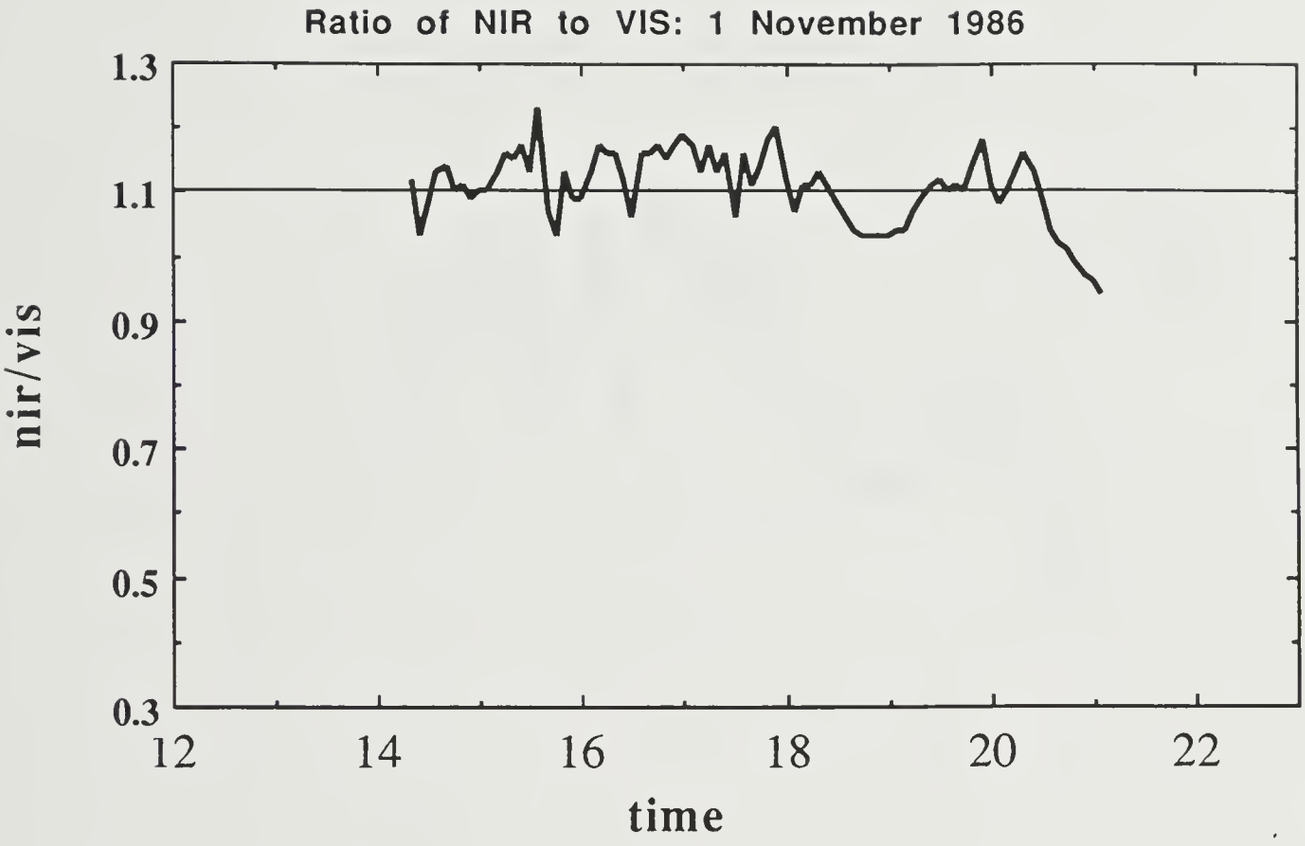

Transmissivity: 31 October 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

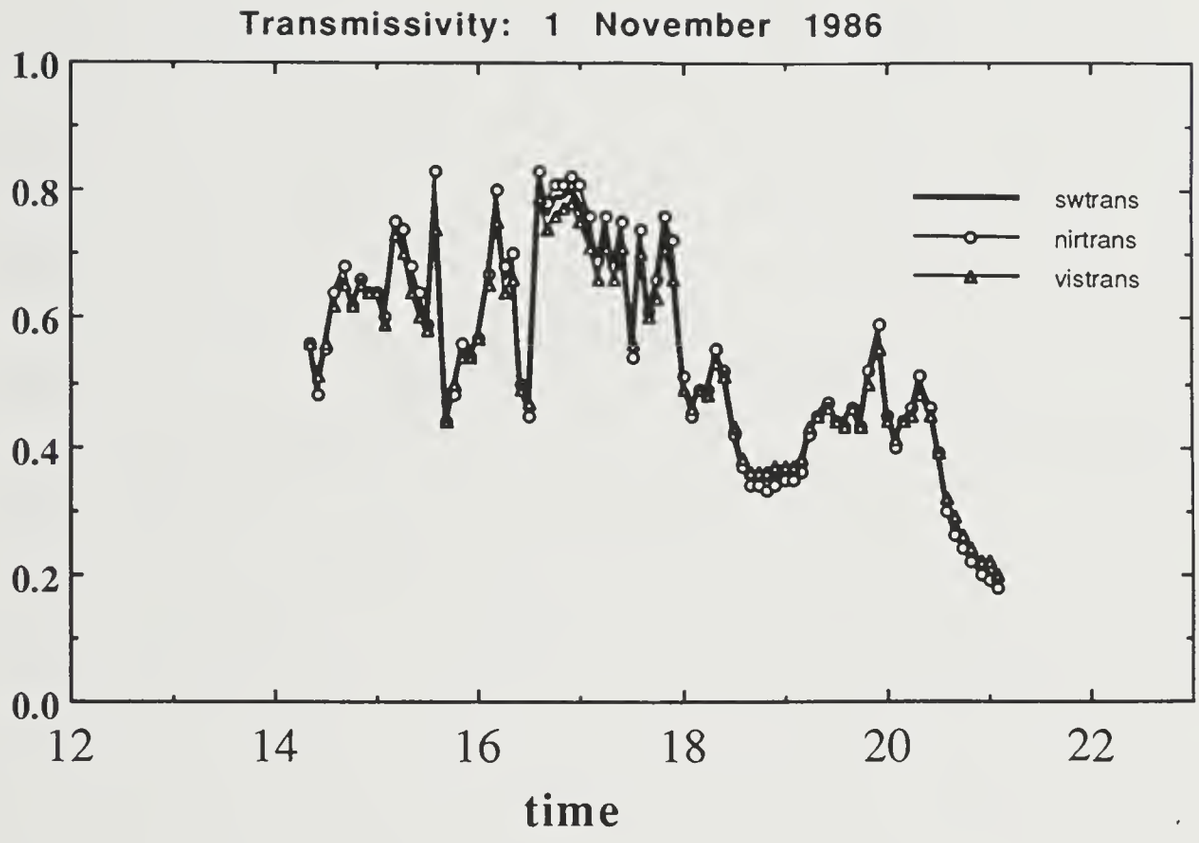

Optical Depth: 31 October 1986
5
4
3
2
1
0
12
14
16
18
20
22
time
swopdep

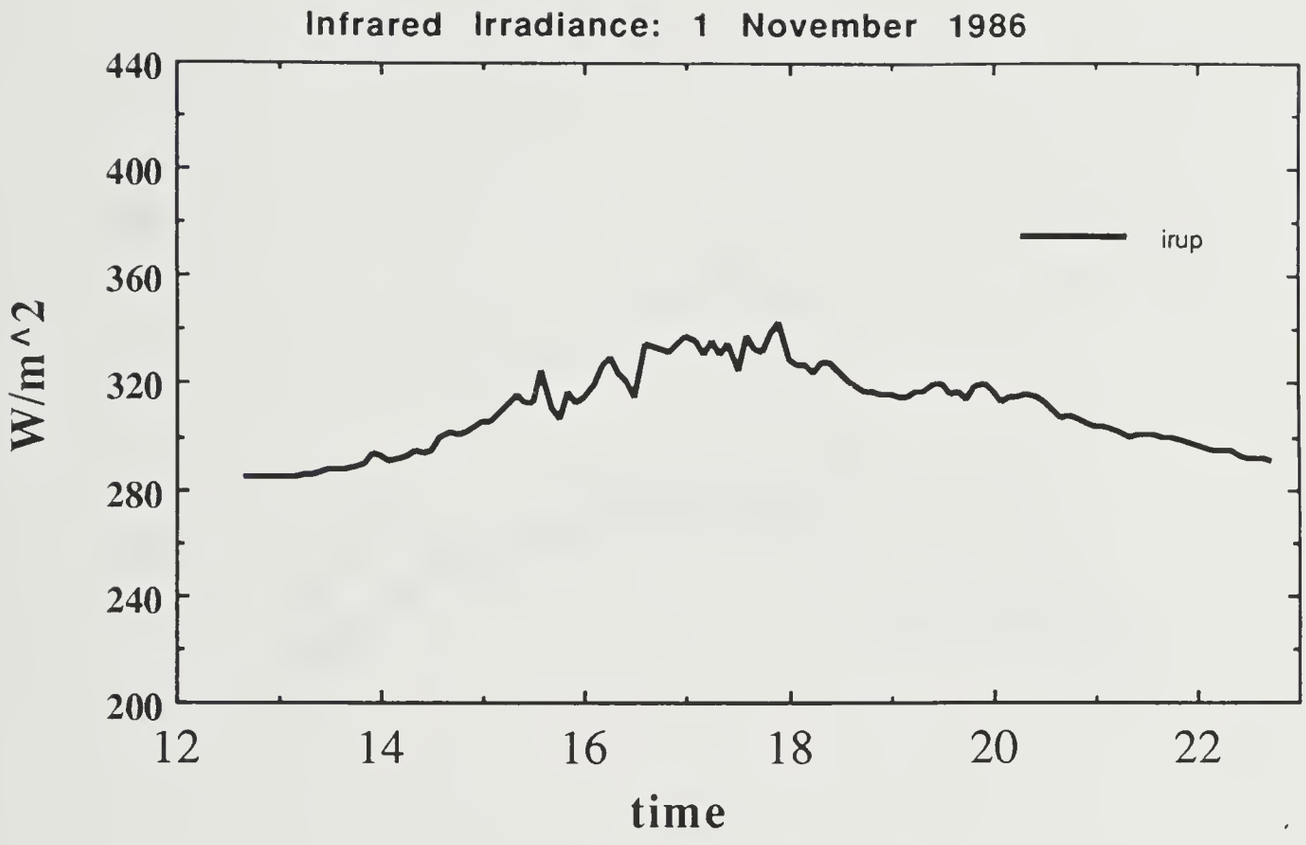

Infrared Irradiance: 31 October 1986
440
400
360
320
280
240
200
W/m^2
irdwn
irup
12
14
16
18
20
22
time

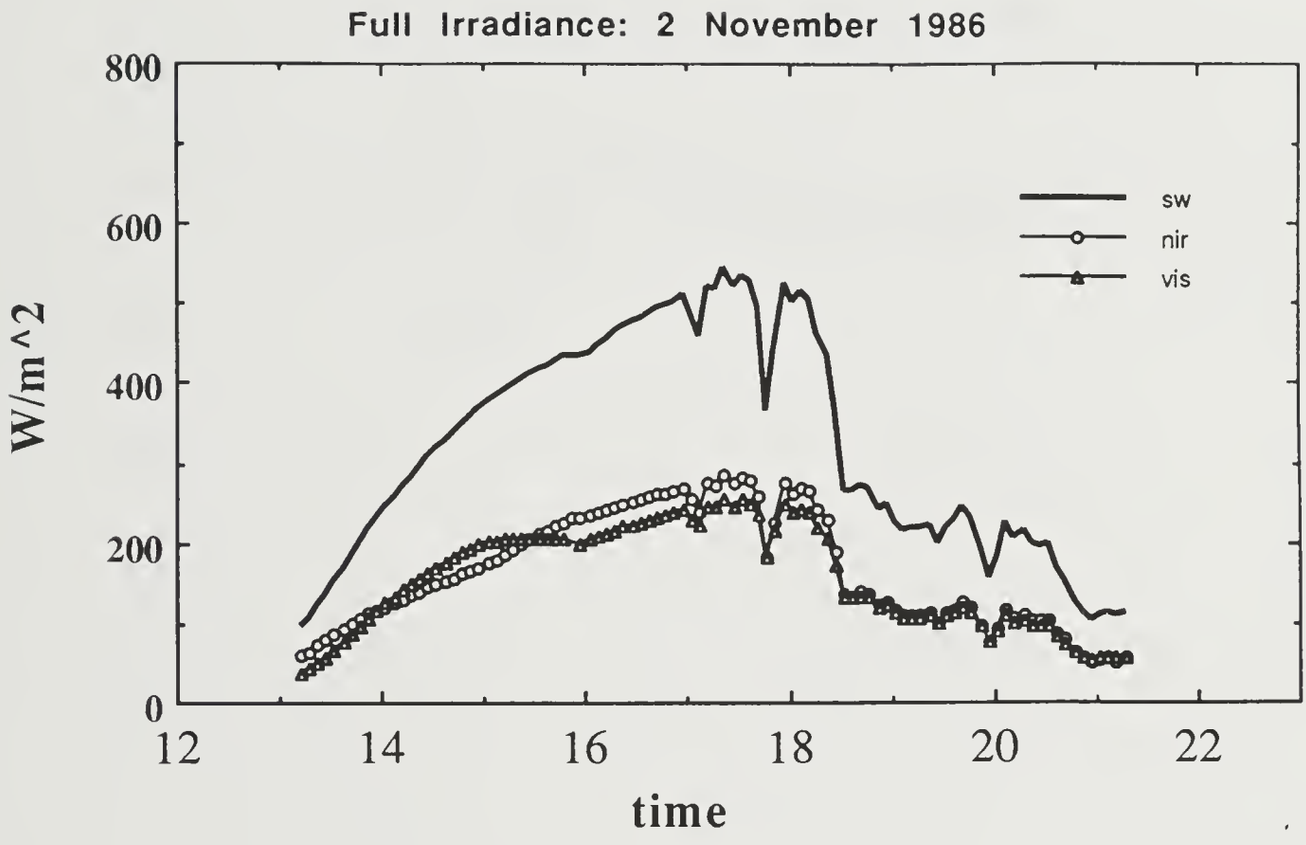

Net Surface Irradiance: 31 October 1986
500
400
300
200
100
0
-100
W/m^2
12
14
16
18
20
22
time

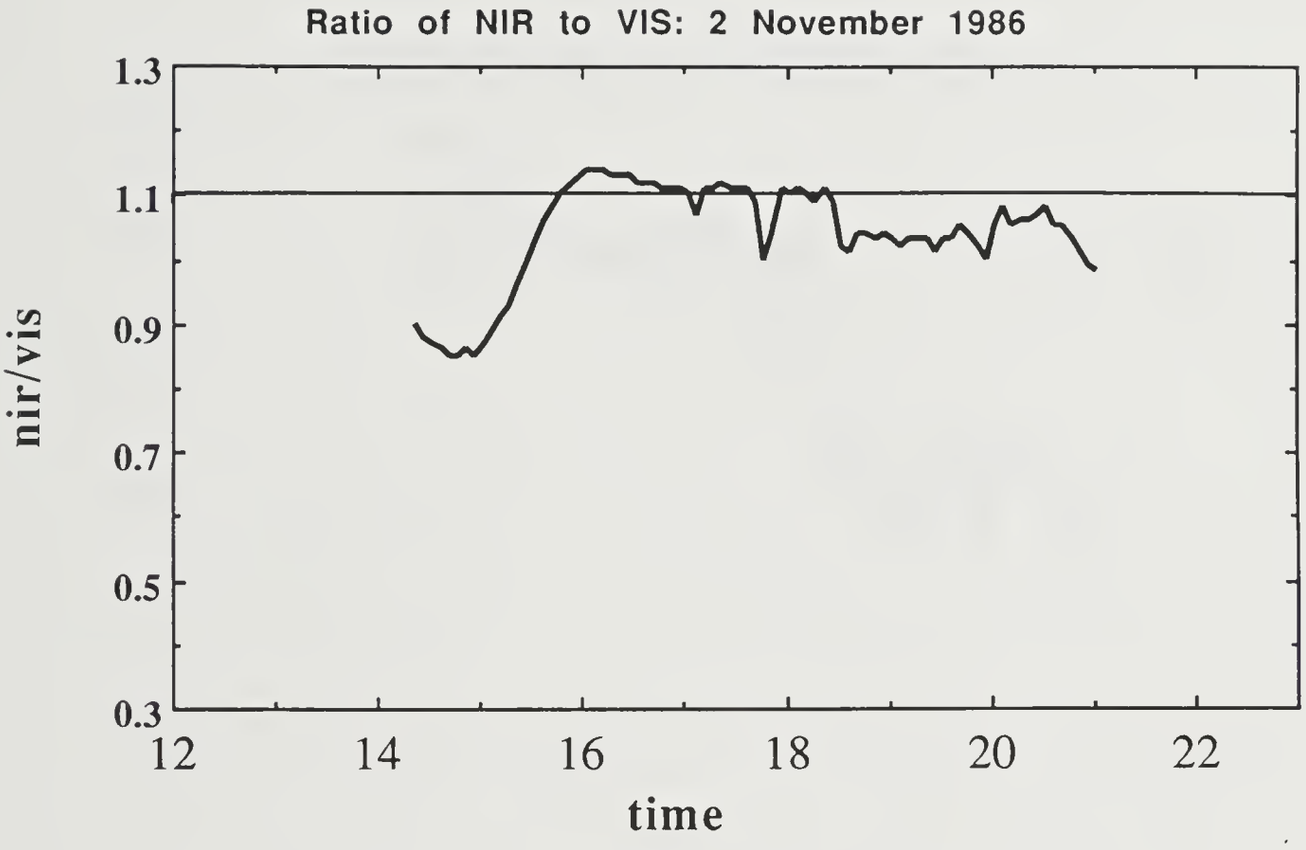

Full Irradiance: 1 November 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

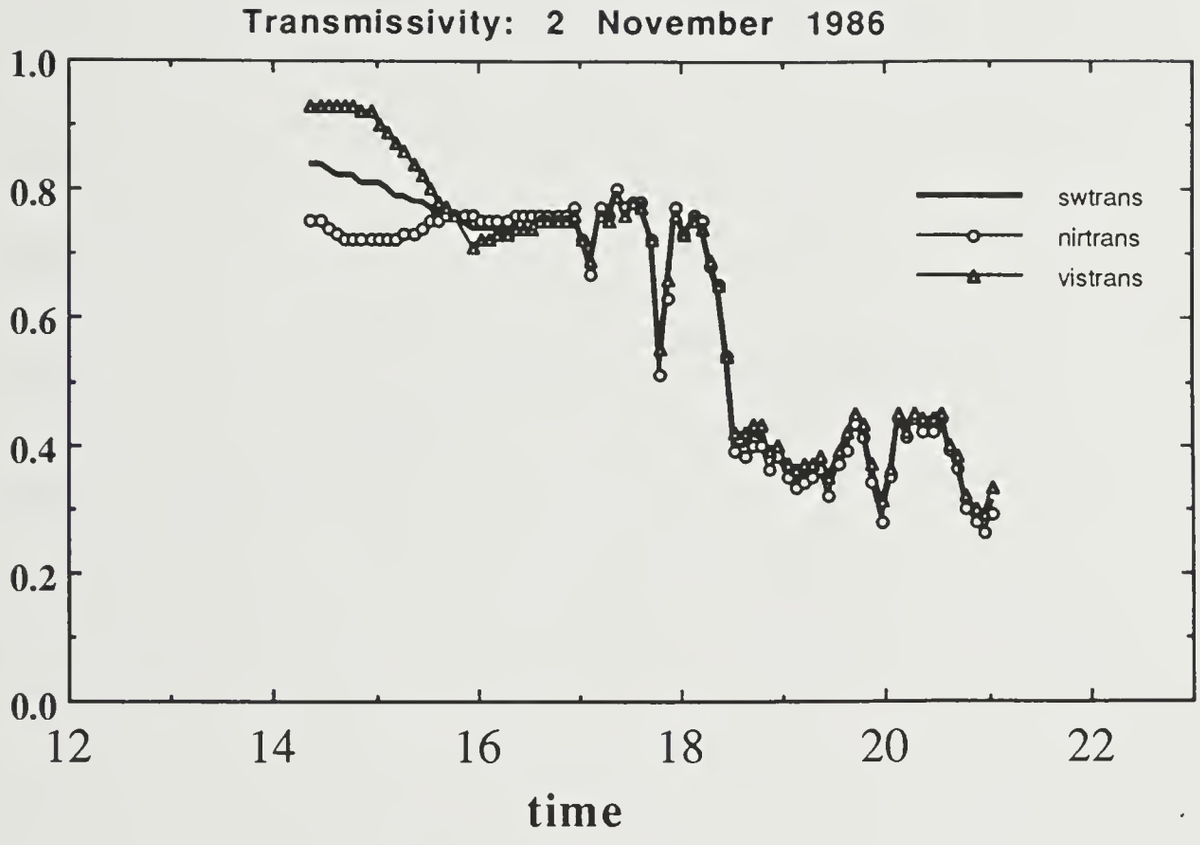

Ratio of NIR to VIS: 1 November 1986
1.3
1.1
0.9
0.7
0.5
0.3
nir/vis
12
14
16
18
20
22
time

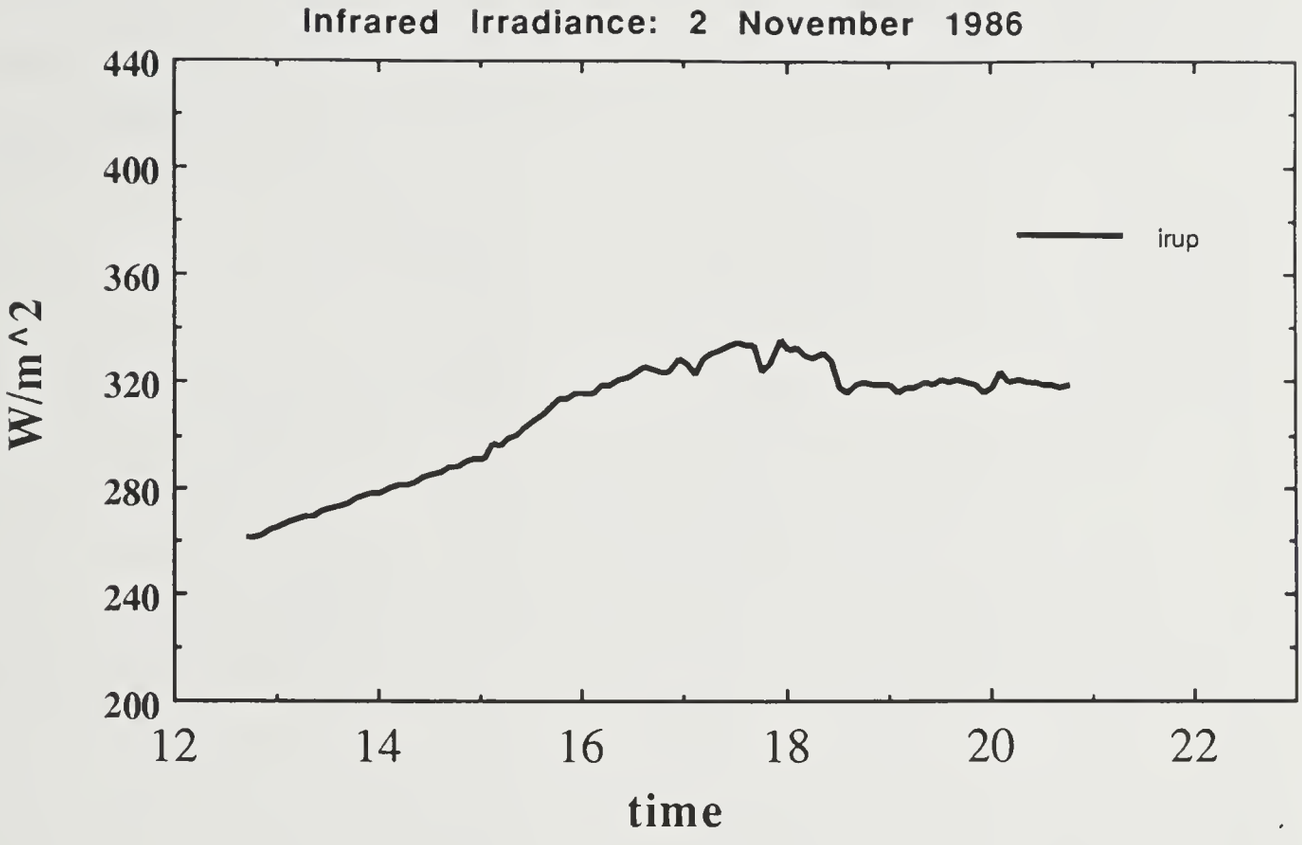

Transmissivity: 1 November 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans


Infrared Irradiance: 1 November 1986
440
400
360
320
280
240
200
W/m^2
irup
12
14
16
18
20
22
time


Full Irradiance: 2 November 1986
800
600
400
200
0
W/m^2
12
14
16
18
20
22
time
sw
nir
vis

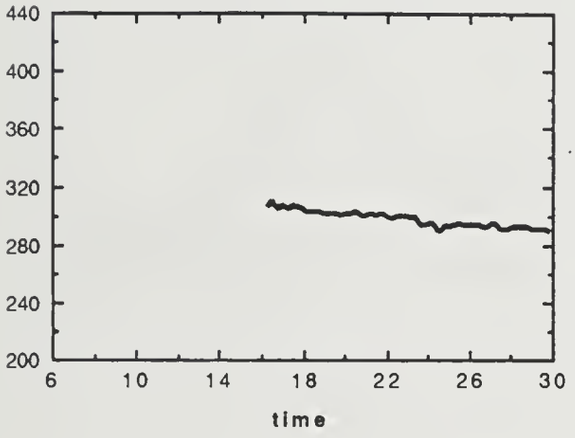

Ratio of NIR to VIS: 2 November 1986
1.3
1.1
0.9
0.7
0.5
0.3
nir/vis
12
14
16
18
20
22
time


Transmissivity: 2 November 1986
1.0
0.8
0.6
0.4
0.2
0.0
12
14
16
18
20
22
time
swtrans
nirtrans
vistrans

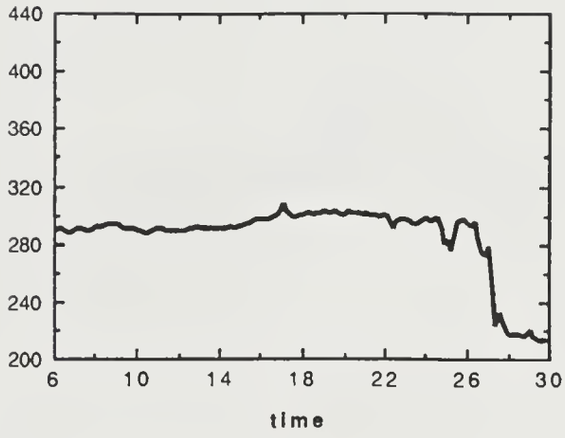

Infrared Irradiance: 2 November 1986
440
400
360
320
280
240
200
W/m^2
irup
12
14
16
18
20
22
time

B) Five minute averages of longwave downwelling and upwelling irradiances for full days. LW down is shown with solid lines, LW up with open circles. Values are in watts/m^2 and time in GMT.

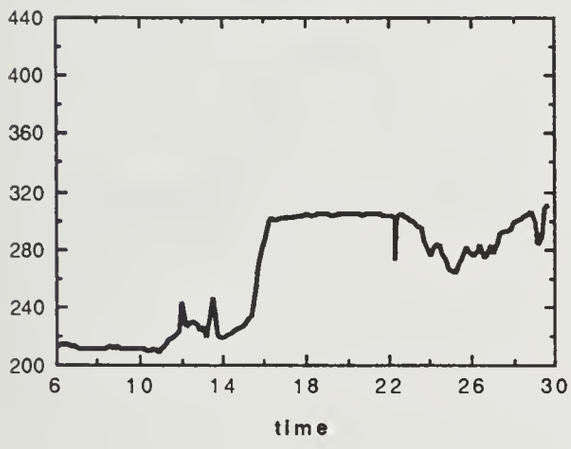
13 October 1986



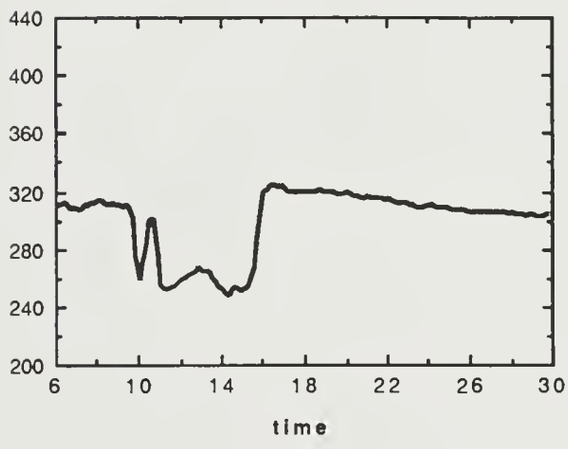
14 October 1986



15 October 1986



16 October 1986



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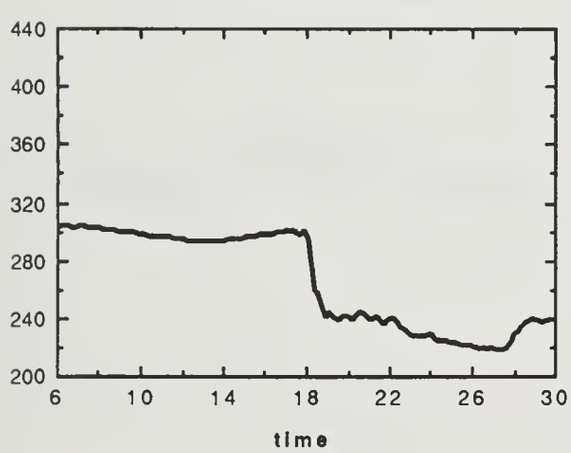

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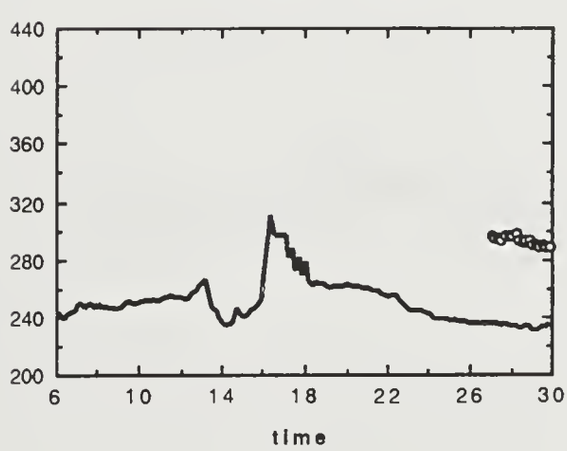
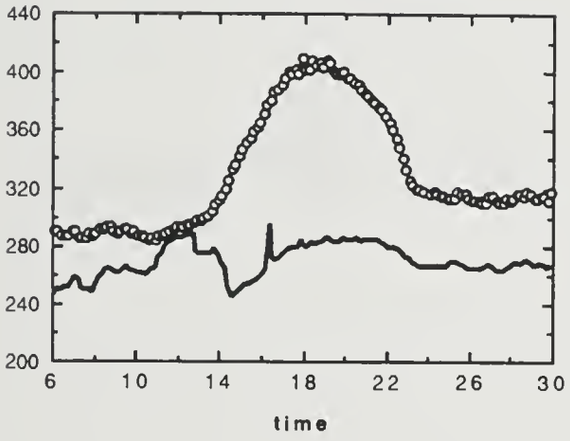


19 October 1986



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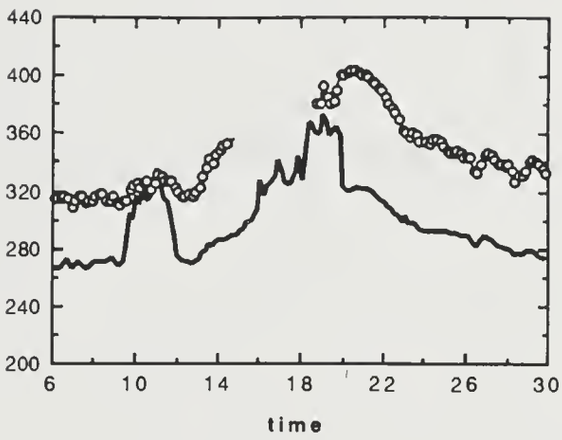

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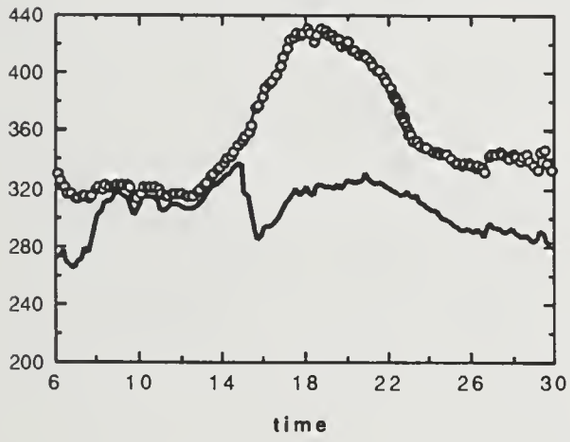

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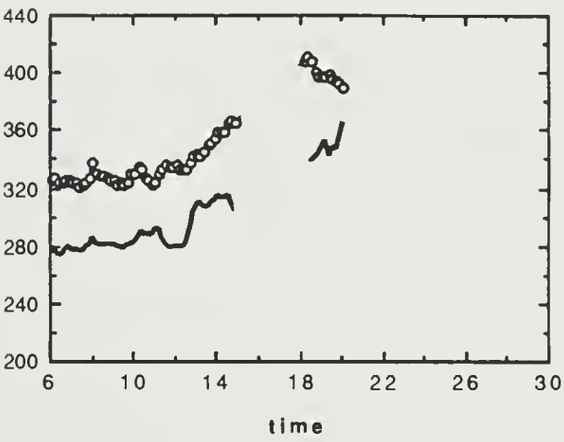

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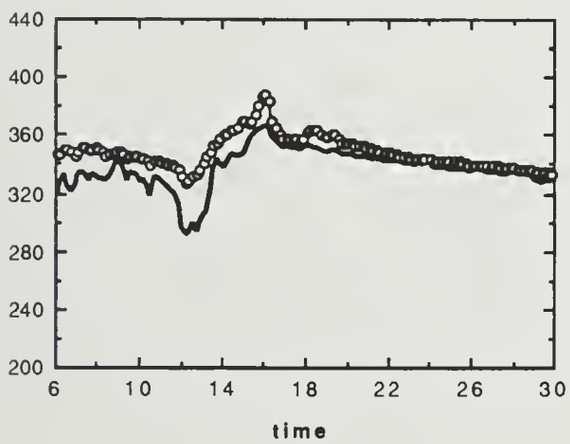

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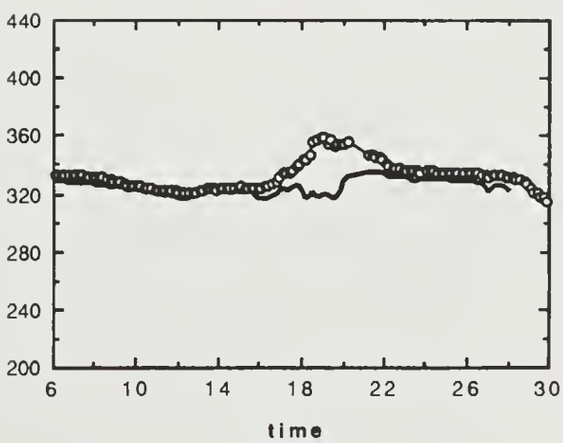

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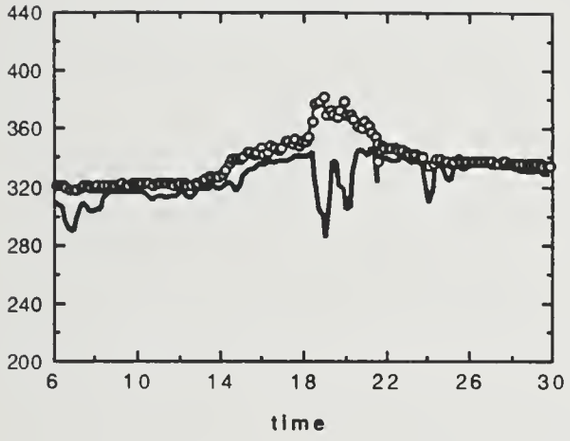

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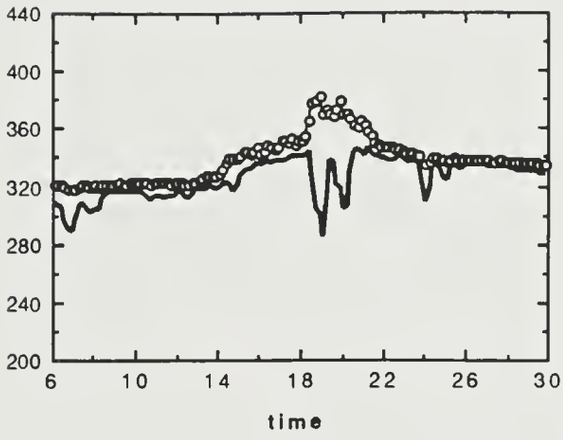

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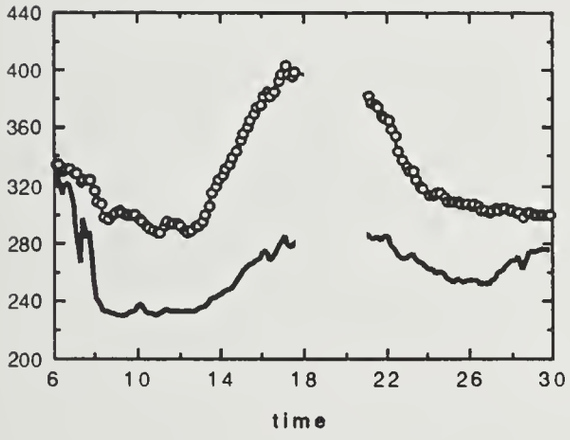

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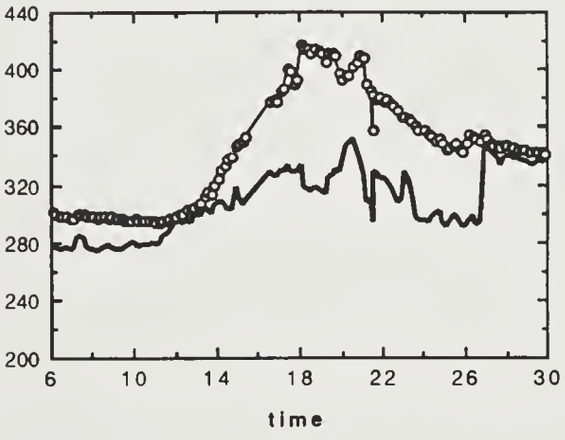

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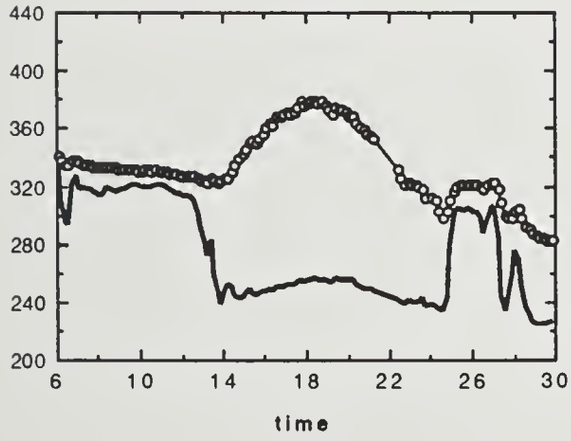

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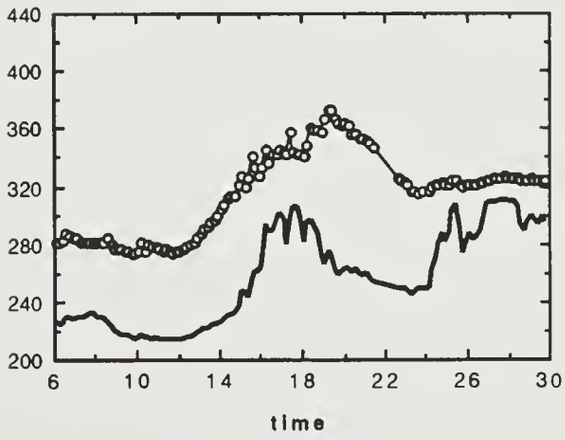

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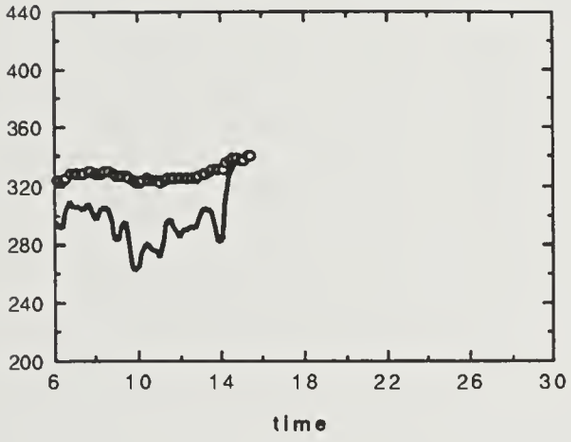

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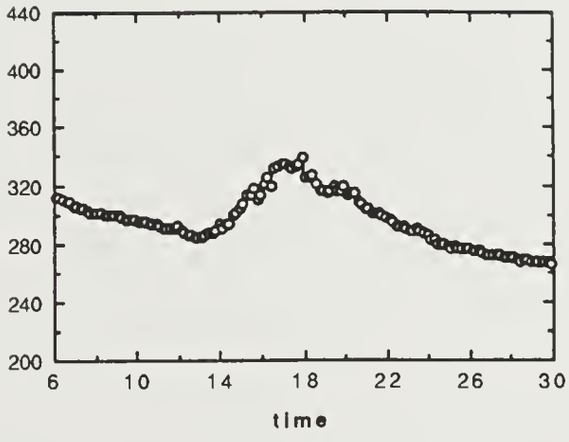

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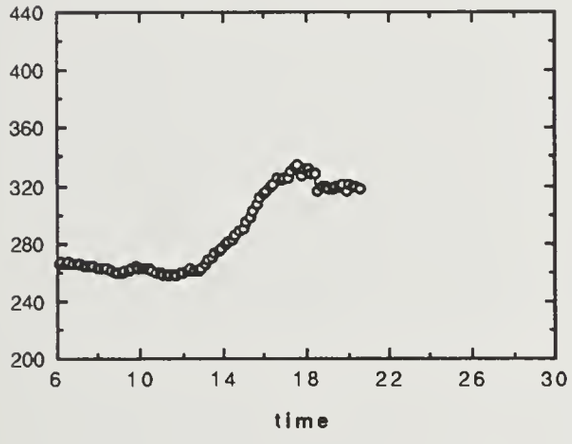

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